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REPORT ON

GROUNDWATER MONITORING PLAN

VULCAN COAL MINE

For: Vitrinite Pty Ltd

Project number: 4041

Date: 09/02/2022

ABN: 50 627 068 866 www.hydrogeologist.com.au info@hydrogeologist.com.au
1/149 Boundary Road, Bardon. QLD. 4065 P.O. Box 108, The Gap. QLD. 4061

Table of contents

Table of contents (continued)

Figure list

Table list

Groundwater Monitoring Plan – Vulcan Coal Mine

Prepared for

Vitrinite Pty Ltd

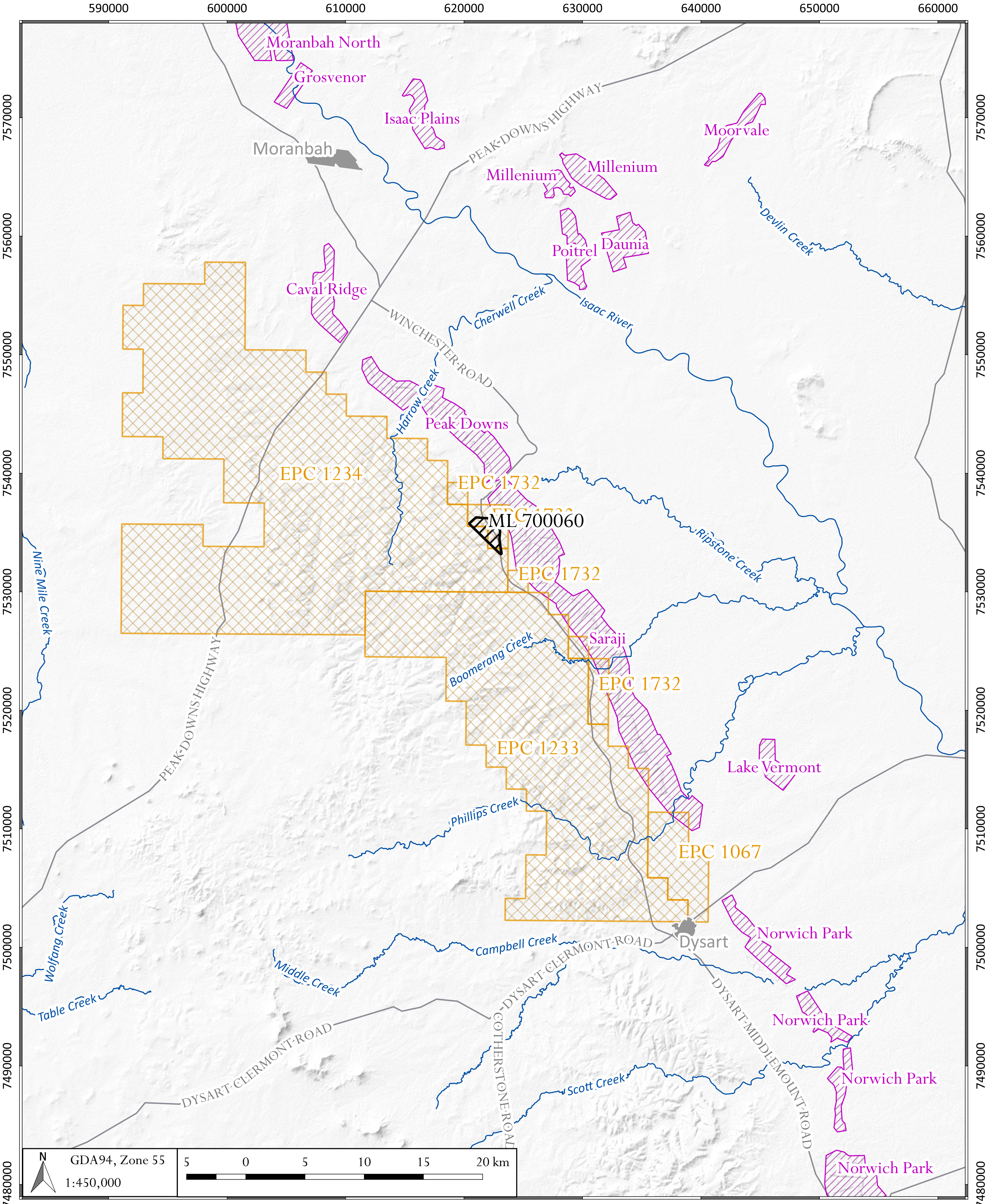
1. Introduction

Mining & Energy Technical Services Pty Ltd (METServe) has been engaged by Queensland Coking Coal Pty Ltd (Vitrinite) to manage the environmental approval process for the Vulcan Coal Mine (VCM). The VCM is located approximately 15 km to the south of the township of Moranbah, within Mining Lease (ML) 700060 (Figure 1.1). This groundwater monitoring plan (GWMP) lists monitoring sites, procedures, and monitoring frequency for the VCM to satisfy conditions within the Environmental Authority (EA) EA0002912 provided by the Department of Environment and Science (DES) on the 27th September 2021.

The Jupiter hard coking coal target has been defined and selected for open cut development via a single pit. The VCM will operate for approximately 4 years and will extract approximately 6 million tonne (Mt) of Run of Mine (ROM) hard coking coal at a rate of up to 1.95 million tonnes per annum (Mtpa). The VCM will target the Alex and multiple Dysart Lower coal seams.

Once waste rock has been removed to expose the coal seam, coal will be extracted utilising truck and shovel mining methods. The coal will be hauled to a ROM pad and processed through dry crushing and screening mobile plant as required. Once crushed and screened coal will be placed on the ROM stockpile for haulage. Rejects from the crushing and screening process will be stockpiled separately and placed within the relevant active dump. There are no coal washing activities, facilities, or processing waste storage planned as part of the VCM.

A small out-of-pit waste rock dump will be established prior to commencing in-pit dumping activities that will continue for the life of the operation. In-pit dumping will then fill the majority of the pit during operations with the remaining final void to be backfilled upon cessation of mining, resulting in the establishment of a low waste rock dump landform over the former pit area. The initial out of rock waste dump will be rehabilitated in-situ.



LEGEND

- Vulcan ML 700060
- Active mine - vicinity of project
- Exploration permit - coal (EPC)
- Town

DATE
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Underground Water Monitoring Plan – Vulcan Coal Mine

Project location

FIGURE No.
1.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.

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2. EA proposed approval conditions

The EA lists eighteen (18) specific conditions relating to groundwater (Table 2.1). In summary, the EA approval conditions prescribe the GWMP; specifying the locations of monitoring points (Table 2.2), sampling frequency (Table 2.2) trigger values for water quality indicators and groundwater hydrochemistry (Table 2.3), and trigger values with respect to groundwater levels (Table 2.4).

Table 2.1 EA groundwater conditions

Condition number		Condition	Refer to Section
E1		All groundwater monitoring data, plans, programs, and reports are to be submitted to the administering authority via WaTERS.	--
E2		The environmental authority holder must not release contaminants, directly or indirectly, to groundwater.	--
E3		Within **five (5) business days** of submitting the notification required by condition **A4**, the environmental authority holder is required to commence monitoring required by condition **E6**.	--
E4		**Baseline Groundwater Monitoring Prior to Commencement of Activities:** A baseline groundwater monitoring program must be developed and implemented by suitably qualified person(s) and be provided to the administering authority at least **twenty (20) business days** prior to commencement of activities (including construction activities, excluding exploration activities). The groundwater program must:	--
	(a)	contain representative groundwater quality samples from the geological units identified as potentially affected by activities;	--
	(b)	include at least **twelve (12)** sampling events from locations detailed in **TABLE E1: Groundwater Monitoring Locations and Frequency**, that are no more than **one (1) month** apart over a **one (1) year** period, so as to determine background groundwater quality;	--4.3.12
	(c)	use a conceptual model to determine the location of groundwater bores;	--
	(d)	include background groundwater quality in hydraulically isolated background bore(s);	--
	(e)	allow for the identification of natural groundwater level trends and groundwater quality trends;	--
	(f)	identify groundwater water level trigger limits as per **Table E2: Groundwater Quality Limits**;	--
	(g)	detail proposed mitigation and monitoring measures to ensure the activity will not impact environmental values;	--
	(h)	detail how impacts to prescribed environmental matters have been or will be avoided as a result of the disturbance with the installation of proposed bores.	--
E5		**Groundwater Quality Limits:** All contaminant triggers from the Baseline Groundwater Monitoring program must be reviewed and submitted to the administering authority via an amendment that is deemed to be a valid application, no more than **eighteen (18) months** from the commencement of activities; to evaluate whether the replacement of interim trigger values for site specific values are appropriate for all parameters specified in **Table E2 - Groundwater Quality Limits**.	4.3 and 5.5
E6		**Groundwater Monitoring:** Groundwater quality and levels must be monitored at the locations and frequencies listed in **Table E1: Groundwater Monitoring Locations and Frequency** for quality characteristics identified in **Table E2: Groundwater Quality Limits.**	--

Condition number	Condition	Refer to Section
E7	A replacement bore for MB04 must be installed in the same coal seam immediately outside the north-east mining footprint and begin collecting data before the decommission of MB04.	--
E8	Two bores must be installed to detect potential seepage down gradient from mine affected water dams MWD1 and MWD3 within **six (6) months** from the commencement of activities notified under condition **A4**.	--
E9	The environmental authority holder must submit values to replace all TBD values in **Table E1: Groundwater Monitoring Locations and Frequency** and **Table E3: Groundwater level monitoring**, within the **nine (9) months** from the commencement of activities notified under condition **A4**.	--
E10	**Assessment Criteria for Bores – Quality Characteristics:** The mining activity must not cause groundwater measured from any bore specified in **Table E1: Groundwater Monitoring Locations and Frequency** to exceed the corresponding Limits specified in **Table E2: Groundwater quality limits** on any **three (3)** consecutive sampling occasions.	--
E11	If the quality characteristics specified in **Table E2 - Groundwater quality limits** are exceeded as conditioned in **E10**, the environmental authority holder must notify the administering authority via WaTERS within **twenty-four (24) hours** of receiving the results.	--
E12	**Assessment Criteria for Bores – Level Trigger:** The mining activity must not cause groundwater measured from any bore specified in **Table E1: Groundwater Monitoring Locations and Frequency** to exceed the corresponding Level trigger thresholds specified in **Table E3: Groundwater level monitoring.**	--
E13	If the Level Trigger Thresholds of groundwater measured at any compliance bore specified in **Table E1: Groundwater monitoring locations and frequency** exceeds any of the corresponding trigger levels specified in **Table E3: Groundwater level monitoring**, the holder of the environmental authority must (a) notify the administering authority via WaTERS within **twenty-four (24) hours** of receiving the results; and (b) conduct an investigation into the cause of the exceedance within **twenty (20) business days.**	--
E14	If an exceedance under condition **E10** and/or **E12** occurs, the environmental authority holder must undertake an investigation to determine that environmental harm has or may occur, and must: (a) implement immediate measures to reduce the potential for environmental harm; (b) develop and detail long-term mitigation measures to address any existing groundwater contamination and prevent recurrence of groundwater contamination; and (c) submit an investigation report to the administering authority within **twenty-eight (28) days** of completion of investigation.	--
E15	**Groundwater Management and Monitoring Program:** Following the commencement of activities in accordance with condition **A4**, the environmental authority holder must: (a) implement the Groundwater Management and Monitoring Program for the entire operational and closure phase of mining; (b) submit a Groundwater Management and Monitoring Program to the administering authority via WaTERS within **twelve (12) months** of commencement date of activities; (c) update the program every **two (2) years** if required**;** and (d) submit all groundwater monitoring data from January to December of the previous calendar year to the administering authority via WaTERS by **1 March** of each calendar year.	--
E16	The **Groundwater Management and Monitoring Program Report** required by condition **E15** must include:	--
	(a) the standing water level of all groundwater bores within **Table E1: Groundwater Monitoring Locations**;	--

Condition number	Condition	Refer to Section
	(b) an assessment of long-term water quality and water level trends at all groundwater bores in **Table E1: Groundwater Monitoring Locations**;	--
	(c) maps showing the actual water level drawdown contours caused by the take of associated water for each groundwater aquifer in accordance with **Table E3: Groundwater level monitoring;**	--
	(d) details of any review undertaken of the numerical groundwater model and conceptual model;	--
	(e) an assessment of any differences between the groundwater level impact predicted and actual impacts for corresponding periods in the most current numerical groundwater model;	--
	(f) details of any bores which are predicted by the most current numerical groundwater model to be located within the depressurisation zone;	--
	(g) identify potential sources of contamination from the mining activity;	--
	(h) identify the environmental values that need to be protected;	--
	(i) ensure that all potential underground water impacts due to the activity are identified, mitigated and monitored;	--
	(j) document sampling and monitoring methodology;	--
	(k) include a conceptual groundwater model;	--
	(l) ensure that monitoring bores are representative of the target aquifer and chemically comparable;	--
	(m) include an appropriate quality assurance and quality control program; and	--
	(n) include a review process to identify required improvements to the program and address any comments provided by the administering authority.	--
E17	Monitoring and sampling of groundwater must comply with the latest edition of the administering authority's Groundwater Monitoring and Sampling Manual.	--
E18	**Bore construction and maintenance and decommissioning:** **The construction, maintenance, management, and decommissioning of groundwater bores (including groundwater monitoring bores) must be undertaken in a manner that prevents or minimises impacts to the environment and ensures the integrity of the bores to obtain accurate monitoring.**	**--**

Table 2.2 Groundwater monitoring location and frequency (Table E1)

Bore	MB04	MB05	MB13	MB x	MB x	MB x
Latitude (GDA94)	-22.27597	-22.28721	-22.29849	TBD	TBD	TBD
Longitude (GDA94)	148.1843	148.1839	148.1934			
Aquifer	Moranbah CM	Back Creek Group	Back Creek Group			
Monitored unit	DLL coal seam*	MAT coal seam**	MAT coal seam**			
Surface RL (mAHD)	243.28	252.70	223.13			
Depth (mbGL)	21.5	40.9	35			
Monitoring Frequency	Monitored monthly per condition **E3**, upon which monitoring occurs quarterly afterwards.					

*Notes: *DLL = Dysart Lower Lower coal seam **MAT = Matilda coal seam mbGL = metres below ground level*
mAHD = metres above the Australian Height Datum Surface RL = Reduced Standing Water Level

Table 2.3 Proposed groundwater quality triggers and limits (Table E2)

Parameter	Bores	Limit	Comments
pH (field) (pH units)	All bores	5.5 - 8.0	Broad range to encompass all bores, adapted from data and ANZG (2018)
Electrical Conductivity (field) (µS/cm)	MB04	12,849*	Site specific 95th percentile
	MB05	2,756*	Site specific 95th percentile
	MB13	3,000*	95th percentile of MB05 rounded up to reduce likelihood of false non-compliance
Metals and Metalloids			
Sulphate (mg/L)	MB04	1.76*	Site specific 95th percentile
	MB05	284*	Site specific 95th percentile
	MB13	398	Deep WQO
Aluminium (dissolved) (mg/L)	MB04	4.8*	Site specific 95th percentile
	MB05	6.2*	Site specific 95th percentile
	MB13	6*	Site specific 95th percentile of MB05 and MB13
Arsenic (dissolved) (mg/L)	All bores	0.013	ANZG (2018)
Iron (dissolved) (mg/L)	MB04	288*	Site specific 95th percentile
	MB05	2.9*	Site specific 95th percentile
	MB13	2.8*	Site specific 95th percentile of MB05 and MB13
Lead (dissolved) (mg/L)	All bores	0.008	ANZG (2018)
Mercury (dissolved) (mg/L)	All bores	0.0006	ANZG (2018)
Molybdenum (dissolved) (mg/L)	All bores	0.034	ANZG (2018)
Selenium (dissolved) (mg/L)	All bores	0.005	ANZG (2018) 99th percentile
**TRH C6-C9 (µg/L)	All bores	< 20	LOR
**TRH C10-C36 (µg/L)	All bores	< 50	LOR

Notes: * *Site specific values using 95th percentiles* ** *Total Recoverable Hydrocarbons (TRH)*

Table 2.4 Groundwater level monitoring (Table E3)

Monitoring location	Monitored unit	Pre-mining baseline level (mAHD)	Level threshold (mAHD)
MB04	DLL coal seam	237.70	236.27
MB05	MAT coal seam	237.13	234.86
MB13	MAT coal seam	202.71	200.44
MBX[2]	DLL coal seam	TBD	TBD
MBX		TBD	TBD
MBX		TBD	TBD

Notes: [1]*90th percentile predicted maximum cumulative drawdown over the life of the Project beyond any background non-mining related influence, except where specifically identified.*
[2] *To replace MB04*

3. Site description

3.1. Climate

Bureau of meteorology (2016) classifies the area around the VCM as subtropical, with mostly hot dry summers and mild winters. In terms of rainfall, the area is classified as summer rainfall dominant with annual rainfall generally between 550 mm and 650 mm, and the majority of the rain falling between November and March. Table 3.1 (and Figure 3.1) summarises the local climatic data obtained by SILO datadrill (Department of Environment and Science & Bureau of Meteorology, 2020) for the VCM (latitude -22.35°, longitude 148.20°, time period January 1889 to January 2020) showing the long term rainfall and evaporation averages.

The average monthly rainfall varies between 16 mm/month in autumn or winter to 109 mm/month in summer. The average annual rainfall is 590 mm, and when comparing precipitation with evaporation (estimated Actual Aerial Evapotranspiration – AAET (Chiew *et al*., 2002)), average evaporation exceeds average precipitation every single month, potentially leading to groundwater recharge deficit. Groundwater recharge events will be limited to either periods of large episodic rainfall or persistent rainfall, as demonstrated in the 2019 comparison between daily precipitation and evaporation (Figure 3.2).

Table 3.1 Average monthly precipitation and evapotranspiration

Month	Mean monthly precipitation (mm)	Mean monthly evapotranspiration (mm)
Jan	109.33	137.43
Feb	99.57	120.71
Mar	65.18	118.57
Apr	31.06	86.62
May	27.98	57.23
Jun	31.23	39.59
Jul	22.05	43.74
Aug	20.14	64.72
Sep	16.77	85.54
Oct	31.47	109.47
Nov	50.28	120.87
Dec	85.35	136.32
Σ	590.41	1120.80
min	16.77	39.59
max	109.33	137.43

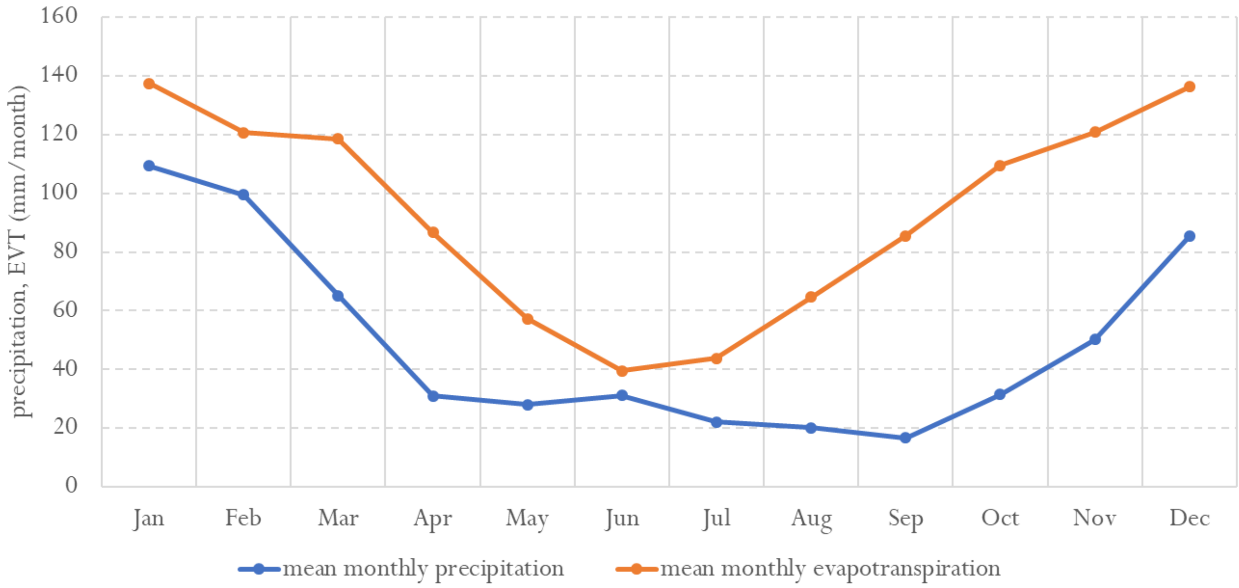


Figure 3.1 Average monthly precipitation and evapotranspiration

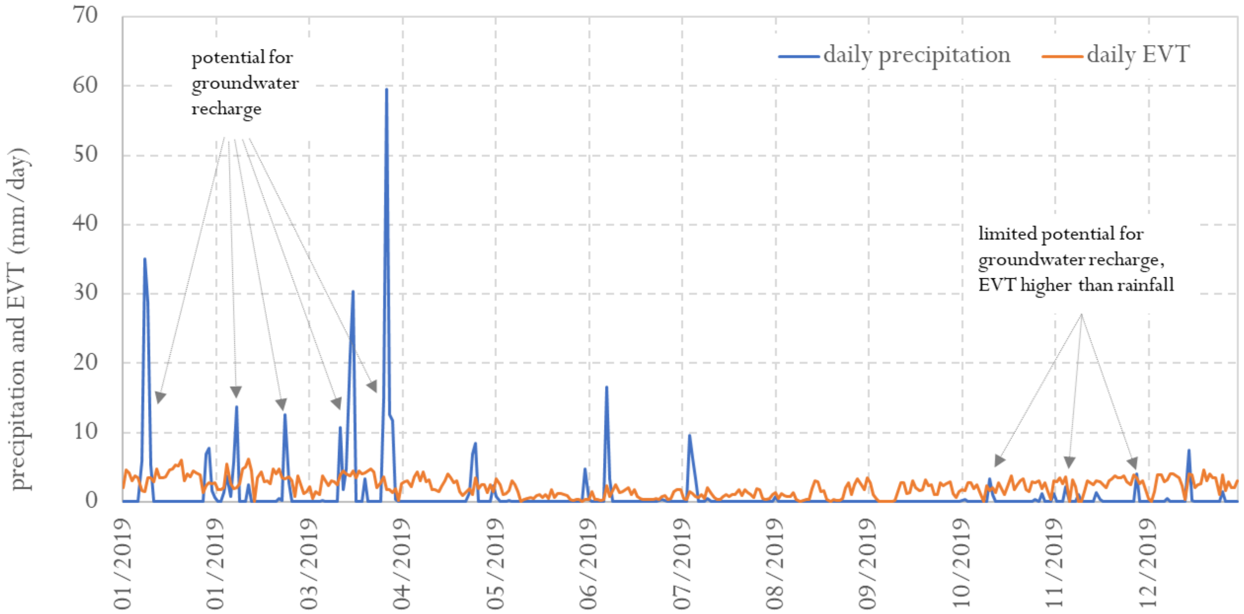


Figure 3.2 Daily precipitation vs. evapotranspiration throughout year 2019

One of the indicators describing long-term precipitation trend is a 'cumulative rainfall departure' – CRD (Xu & Tonder, 2001). The CRD indicates 'drier' periods (periods of lower than average rainfall) by downwards direction of the indicator line. Conversely, 'wetter' periods (periods of higher than average rainfall) are indicated by upward direction of the indicator line. The CRD calculation was based on the monthly averages calculated over the full time period of available data (131 years – see Table 3.1).

For example, the trends represented by CRD analysis (Figure 3.3) show long-lasting dryer than average conditions between 1918 to 1940, 1960 to 1971, and 2001 to 2007, with above average rainfall between 1953 to 1960, 1973 to 1979, and 2007 to 2011. Periods of approximately average rainfall can be observed between 1941 to 1944, 1970 to 1973, 1982 to 1988, and 2011 to 2017. The area around the VCM has recently (beginning of 2018 till end of 2019) gone through a lower-than-average precipitation period.

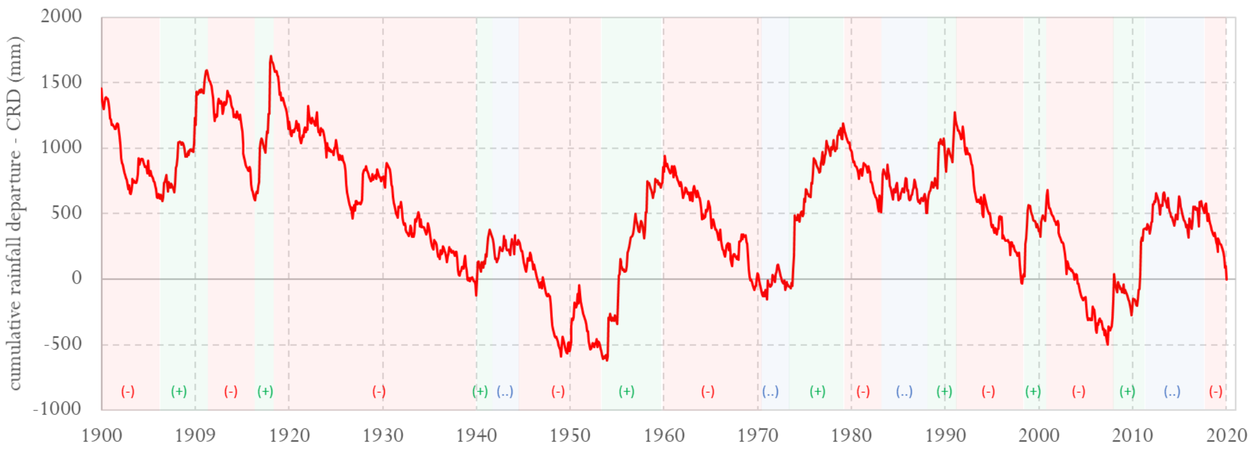


Figure 3.3 Precipitation trend – cumulative rainfall departure (CRD)

3.2. Land use

Land use in the region is dominated by coal exploration and mining, beef cattle grazing, and CSG exploration and operations. Figure 1.1 shows the distribution of mines in the region.

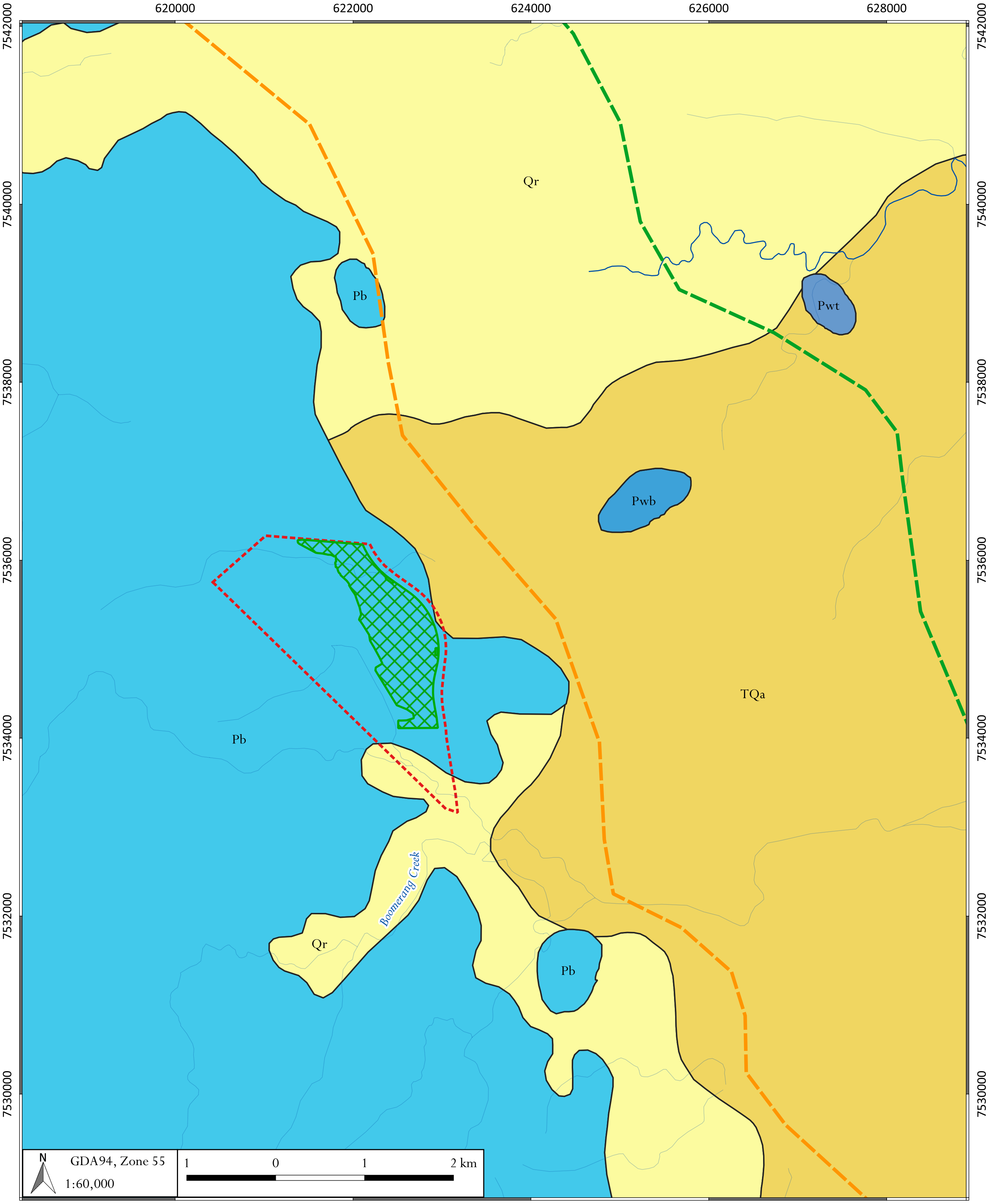
The individual coal mines in close proximity to the VCM are the BHP Saraji Mine and BHP Peak Downs Mine. Caval Ridge Mine is located to the north of Peak Downs Mine and Norwich Park Mine is located to the south of Saraji Mine. These series of coal mines are owned by BHP, however Norwich Park Mine is currently in care and maintenance.

Peak Downs Mine and Saraji Mine commenced coal production in the early 1970s with mining covering an area some 50 km in length and 2 km to 5 km in width. The mines generally follow the strike of the coal seams within the Permian Moranbah Coal Measures and the mines extract coal seams that are stratigraphically higher in the Moranbah Coal Measures than the coal seams to be mined as part of the VCM.

3.3. Geology

The VCM is located on the western limb of the northern Bowen Basin, in a northerly plunging syncline, and at the southern end of the Collinsville Shelf (AECOM, 2016). The target coal seams are subcropping in a north-west to south-east direction, dipping to the north-east.

The VCM targets the Moranbah Coal Measures, specifically the Dysart Lower-Lower (DLL) coal seam, located in the lower part of Moranbah Coal Measures sedimentary sequence (see Figure 3.4). The stratigraphy of the region is presented inTable 3.2, the table also highlights stratigraphic units presented on the VCM site (local context). Only those stratigraphic units present in the local area are described below.



LEGEND

Geology

- TQa - Tertiary regolith
- Qr - Colluvium and residual soils
- Pb - Back Creek Group
- Pwb - Moranbah Coal Measures
- Pwt - Fort Cooper Coal Measures

- Vulcan ML 700060
- Vitrinite VCM Pit

Stratigraphic boundary:

- Back Creek Group - Moranbah Coal Measures
- Moranbah Coal Measures - Fort Cooper Coal Measures

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08/02/2022

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Underground Water Monitoring Plan – Vulcan Coal Mine

Geology of the Project area

FIGURE No.
3.4

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.

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Table 3.2 Interpreted regional and local stratigraphy

Period	Group	Unit	Regional context	Local context
Quaternary		alluvium	✔	✘
Tertiary		regolith*	✔	✔
		Suttor & Duaringa Formations	✔	✘
		basalts	✔	✘
Triassic		Moolayember Formation	✔	✘
		Clematis Sandstone	✔	✘
		Rewan Group	✔	✘
Permian	Blackwater Group	Rangal Coal Measures	✔	✘
		Fort Cooper Coal Measures	✔	✘
		Moranbah Coal Measures	✔	✔
	Back Creek Group	German Creek Formation	✔	✘
	Back Creek Group Exmoor Formation	Dingo Sandstone	✔	✔
		Dingo Siltstone	✔	✔
		Wallaby Hill Sandstone	✔	✔

3.3.1. Tertiary regolith

Tertiary aged regolith (or sediments) is mapped as present within and to the east of the VCM. It is generally described as clay, silt, sand, gravel and colluvial and residual deposits with a predominantly clay matrix. AECOM (2016) refer to the Tertiary aged regolith as unconsolidated to consolidated fluvial, heterogeneously distributed sand deposits separated by a low permeability clay-rich matrix. There is an unconformable contact between underlying Permian coal measures and Tertiary; the boundary representing erosional surface before the deposition of Tertiary sediments.

Typically, the Tertiary sediments are less than 15 m thick although thicknesses of up to 57 m were reported at the Saraji Mine. The presence of paleo-channels and lensing of units within the Tertiary prevent correlation of discrete units; individual units are laterally discontinuous with varied thickness (AECOM, 2016).

Locally, no Tertiary sediments are observed within the VCM , however a regolith profile developed during the Tertiary is present in the drill logs. This Tertiary weathering is evident regionally (AECOM, 2016) and the lithologies can vary from heavily leached, mottled white and maroon clays to sandy clays.

3.3.2. Permian coal measures

The VCM targets the DLL coal seam of the Moranbah Coal Measures. Outcropping at surface to the west of the VCM is the basal section of the Moranbah Coal Measures, locally mapped by Vitrinite as a sequence of sandstones and siltstones. This sequence is capped in a resistant, quartzose medium to coarse grained sandstone, locally referred to as the Mesa Sandstone due to its presence as characteristic mesa plateaus. The base unit of the Moranbah Coal Measures is locally referred to as the Mesa Siltstone (Tom O'Malley, Vitrinite, per.comm., 2019).

The target DLL coal seam was formed as a sequence of four plies (combined thickness of 2.5 m); and a separate basal ply, with good quality coal. The overall thickness of the coal sequence is approximately 3.5 m. The sedimentary sequence dips approximately in an easterly direction at about 4°. East of the VCM, at the Saraji Mine, the Permian coal measures are generally undisturbed and have a gentle regional dip of 2° to 5° towards the east (AECOM, 2016).

3.4. Hydrostratigraphy

The objective of the GWMP is to monitor and assess the pre-development groundwater conditions across the VCM area so that baseline environmental condition can be established. The GWMP will enable changes resulting from the VCM to be assessed and will provide the information to establish whether there has been environmental harm and associated impact to the environmental values within and surrounding the VCM.

Within the VCM, the groundwater generally occurs within three hydrostratigraphic units, as outlined below and shown in Table 3.3:

- the Tertiary regolith,
- the Moranbah Coal Measures; and
- the underlying Back Creek Group.

Table 3.3 Local hydrostratigraphic units

Age	Stratigraphic unit	Lithology	Aquifer type
Tertiary	Unconsolidated, semi-consolidated sediments; weathered profile	Clay, silt, sand, gravel, colluvium, fluvial and lacustrine deposits including cross-bedded quartz sandstone, conglomerate, claystone	Unconfined, poor aquifer, aquitard
Late Permian	Moranbah Coal Measures	Coal, sandstone, siltstone, mudstone, carbonaceous mudstone	Confined aquifer (coal) and confining unit (interburden)
Middle Permian	Back Creek Group	Sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite	Confining unit

3.4.1. Tertiary regolith

Tertiary regolith is mapped within the VCM and Tertiary sediments are mapped at the nearby Saraji Mine and further to the east. The Tertiary regolith and sediments consist of lenses of palaeochannel gravels and sands separated by sandy silts, sandy clays and clays with thicknesses up to 30 m. The silts and clays are densely compacted, hard and generally dry. Potential for groundwater exists within sandy and gravely sections either under unconfined or confined conditions, depending on location. Most of the clean sand and gravel lenses are permeable but are of limited lateral and vertical extent (URS, 2009).

Recharge to the Tertiary regolith and sediments is likely from creek flow (losing ephemeral streams) and from surface infiltration of rainfall and overland flow. Recharge may also occur by downward vertical seepage from overlying Quaternary alluvium (URS, 2009) where the alluvium is present. Given the clayey nature of the Tertiary regolith and sediments it would be expected that recharge rates would be very low.

Discharge from the Tertiary regolith and sediments, where they outcrop and the water table is shallow, may occur through evapotranspiration. The Tertiary sediments may also discharge to the Permian coal measures as, in general, there is a downward vertical hydraulic gradient between the Tertiary and Permian coal measures.

Current groundwater level observations (hydrogeologist.com.au, 2019) from the bores in the vicinity of the VCM indicate that the Tertiary regolith is mostly unsaturated.

3.4.2. Moranbah Coal Measures

Throughout the Bowen Basin, the Permian coal seams are considered to be poor aquifers with the adjacent overburden and interburden sediments generally considered as aquitards. The coal seams generally are considered dual-porosity strata where primary-porosity is provided by the matrix and a secondary porosity is the result of the presence of fractures (joints and cleats). Natural cleats within the coal seams are likely the dominant space for groundwater storage; the main pathway for groundwater movement is dependent on fracture interconnectivity (AECOM, 2016; URS, 2009). The non-coal bearing overburden and interburden units comprise claystone, mudstone, sandstone, siltstone, and shale. These low permeability rock types do not have a good potential for transmitting groundwater.

The DLL coal seam forms a confined, poor quality aquifer. The coal seam is laterally extensive along the western and eastern margins of the Bowen Basin and within the VCM area but with varying thickness. The Permian coal measures within the VCM are known to be partially unsaturated (hydrogeologist.com.au, 2019) and site-specific monitoring bores (i.e. MB1, MB2, MB3 and MB11) have confirmed this.

Groundwater recharge to the Permian coal measures is likely from creek flow events and from surface infiltration of rainfall and overland flow, where the Permian coal measures are exposed, and no substantial clay barriers occur in the shallow sub-surface. Recharge may also occur from overlying Tertiary sediments under downward vertical hydraulic gradient and along faults and other structural features (AECOM, 2016).

Discharge from the Permian coal measures, where they outcrop and the water table is shallow, may occur through evapotranspiration or along faults and by groundwater extraction from bores and mine dewatering/depressurisation (AECOM, 2016; HydroSimulations, 2018). For the shallower coal measures, groundwater elevations are generally at or below groundwater elevations within the overlying unconfined sediments, indicating a downward hydraulic gradient. With increased depth of cover and pressure, the hydraulic gradient within the Permian coal measures may reverse coinciding with a decrease in hydraulic conductivity with depth (HydroSimulations, 2018).

3.4.3. Back Creek Group sediments

The Back Creek Group outcrops to the west of the VCM. The Exmoor and Blenheim Formations of the Back Creek Group are currently interpreted to be conformably underlying the Moranbah Coal Measures. The top of the Exmoor Formation is characterised by prominent coarse-grained siliceous boulder sandstone in outcrop, whilst the top of the Blenheim Formation is easily identifiable by the stratigraphic marker of the fossiliferous and worm burrowed sandstone, locally termed the Worm Burrow Sandstone. Coal seams within the Back Creek Group include the MAY coal seam that has been interpreted to be within the Dingo Siltstone of the Exmoor Formation, and the MAT coal seam within the MAT Siltstone of the Blenheim Formation.

The Back Creek Group comprises sandstone, siltstone, shale and minor coal; and is considered a semi-pervious lower boundary for groundwater flow to the overlying Blackwater Group (URS, 2012). The Exmoor Formation of the Back Creek Group is locally mapped by Vitrinite as the Dingo Sandstone, Dingo Siltstone and Wallaby Hill Sandstone (from top down) and contains recognised and laterally extensive coal seams (MAY and MAT seams). Horizontal hydraulic conductivities have been assessed to be between 1×10^{-4} m/d and 1×10^{-2} m/d.

3.5. Groundwater dependent ecosystems

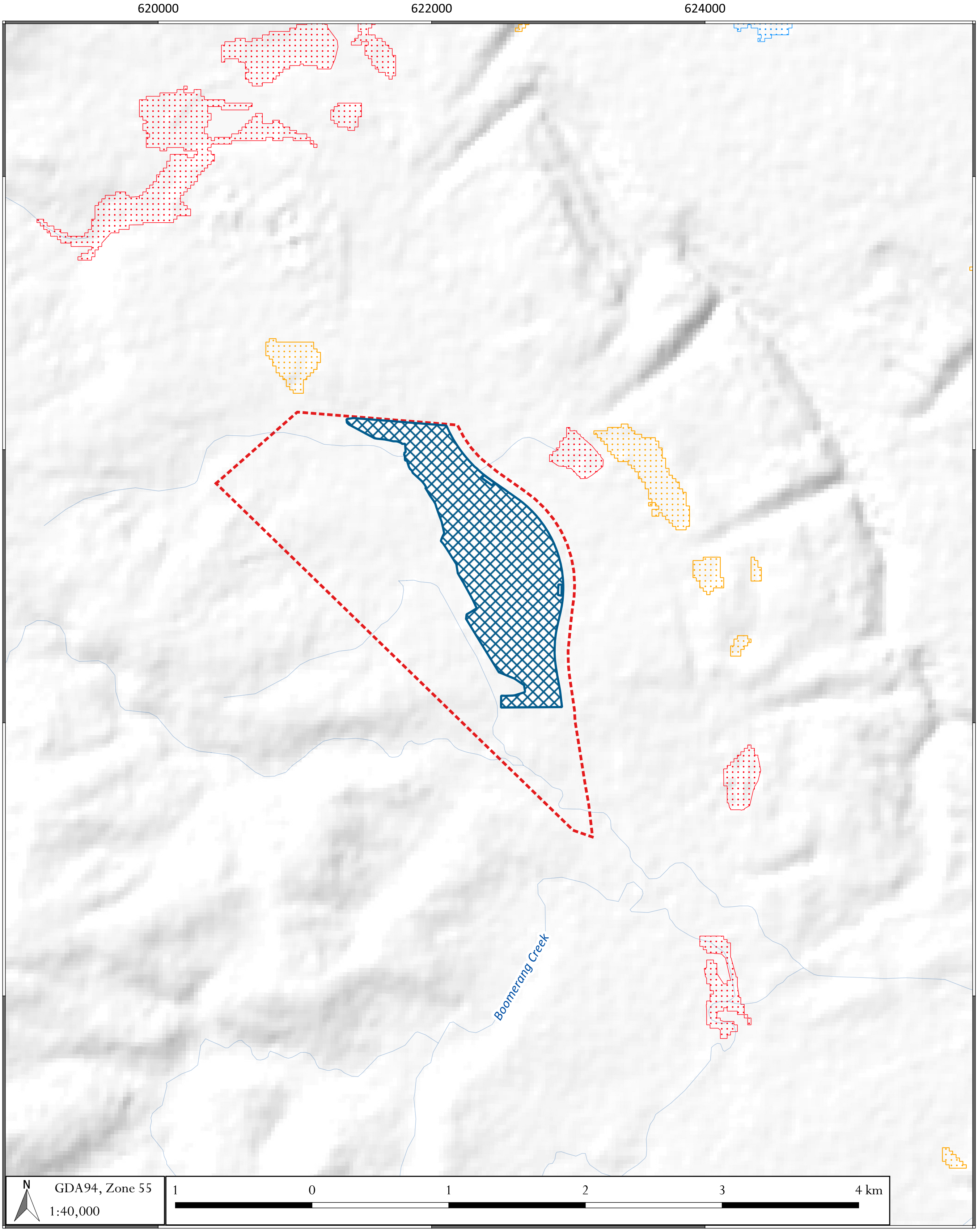
A groundwater dependent ecosystem (GDE) is an ecosystem that requires access to groundwater on a permanent or intermittent basis to meet all, or some of their water requirements. For GDEs such as springs, wetlands, rivers and vegetation, groundwater plays an important role in sustaining aquatic and terrestrial ecosystems. A GDE therefore is a plant and/or animal community that is dependent on the availability of groundwater to maintain its structure and function.

The GDE Atlas (Bureau of Meteorology, 2019) was developed as a national dataset of Australian GDEs to inform groundwater planning and management. It is the first and only national inventory of GDEs in Australia. The GDE Atlas classifies ecosystems based on the potential for dependence on groundwater based on multiple lines of scientific evidence, to high, moderate or low potential:

- high potential for groundwater interaction (indicating a strong possibility the ecosystem is interacting with groundwater);
- moderate potential for groundwater interaction; or
- low potential for groundwater interaction (indicating it is relatively unlikely the ecosystem will be interacting with groundwater.

Bureau of Meteorology (BOM) maps areas for both aquatic and terrestrial GDE indicating the following are mapped in the vicinity of the VCM:

- Aquatic GDEs rely on the surface expression of groundwater, including surface water ecosystems which may have a groundwater component, such as rivers, wetlands and springs. Aquatic GDEs are mapped nearby the VCM as having moderate or high potential to be associated with the surface expression of groundwater (Figure 3.5). The majority of these features appear to be manmade impoundments associated with mining or pastoral industries.
- Terrestrial ecosystems rely on the subsurface presence of groundwater, this includes all vegetation ecosystems. Terrestrial GDEs are mapped nearby the VCM as low to high potential to be dependent on the subsurface expression of groundwater (Figure 3.6). The mapped Terrestrial GDEs are all located upstream of the VCM. No subterranean GDEs (cave and aquifer ecosystems) have been identified by BOM in the vicinity of the VCM.



LEGEND

Aquatic groundwater dependent ecosystems:
- High potential GDE - from national assessment
- Low potential GDE - from national assessment
- Moderate potential GDE - from national assessment

- Vitrinite VCM Pit
- Vulcan ML 700060

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Aquatic groundwater dependent ecosystems

FIGURE No.
3.5

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.
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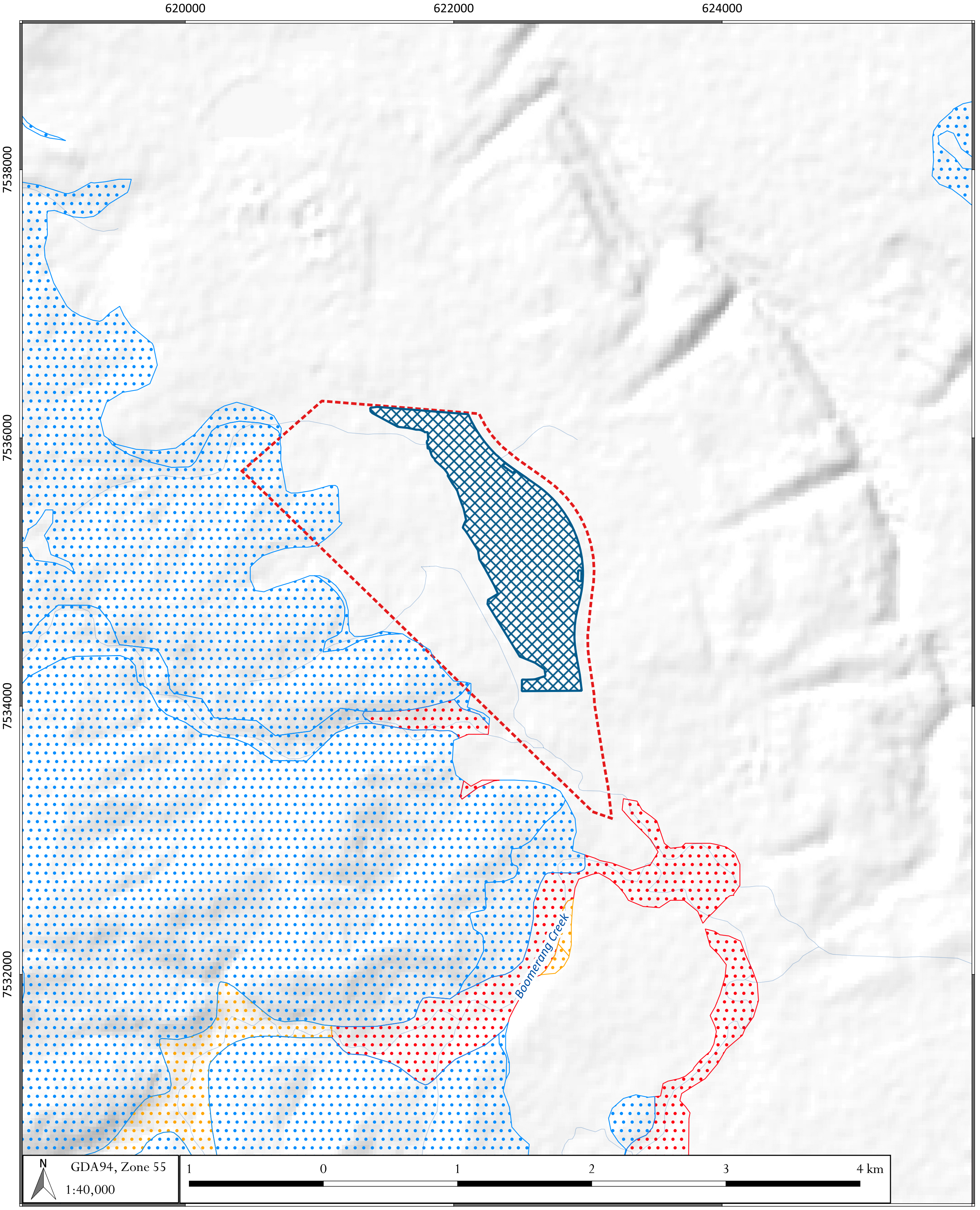

LEGEND

Terrestrial groundwater dependent ecosystem:
- High potential GDE - from national assessment
- Low potential GDE - from national assessment
- Moderate potential GDE - from national assessment

- Vulcan ML 700060
- Vitrinite VCM Pit

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Underground Water Monitoring Plan – Vulcan Coal Mine

Terrestrial groundwater dependent ecosystems

FIGURE No.
3.6

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.

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3.6. Conceptual model

A conceptual model presents a simplified version of the hydrogeological framework and hydraulic processes. It is based on understanding of local geology (Section 3.3), hydrostratigraphy and groundwater flow conditions (Section 3.4). The conceptualisation was undertaken on regional scale in order to capture structures and processes in adjacent sections of the groundwater flow system to the VCM and it is summarised in the west to east cross-section (Figure 3.7). On the figure, the VCM is labelled as 'Vulcan complex'.

The groundwater table is hosted by several units, from the outcropping/sub-cropping Back Creek Group in the west through the Tertiary sediments and Moranbah Coal Measures to the Fort Cooper Coal Measures in the east. As a result of the sloping groundwater table and the easterly dip of the hydrogeological units, some of the units may be partially unsaturated, particularly in the west.

A minor component of rainfall recharge acts on the top of the land surface to provide an input to the groundwater system. Evapotranspiration occurs from groundwater that is shallow, however the groundwater table is often deep, so significant evaporation is likely only from the proposed and existing nearby mine pits. The interaction between surface and groundwater is insignificant within the VCM site domain. The western boundary is a catchment and groundwater divide in the Harrow Range and the eastern boundary is the Jellinbah Thrust Fault/Zone.

Near the VCM and adjacent Saraji Mine, the Moranbah Coal Measures, down to the DLL coal seam (VCM) and DL coal seam (at Saraji Mine) are depressurised and dewatered. Because of the low hydraulic conductivity and transmissivity, and the low storage of the units within the Moranbah Coal Measures, the cones of depression surrounding the mines are expected to be deep (to pit depth) but laterally limited. Once mining related depressurisation and dewatering stops, groundwater will start to recover and eventually will reach steady state in the backfilled material within the former pits, depending on the rate of inflow (rainfall and groundwater inflow) and outflow (evaporation) from the pits.

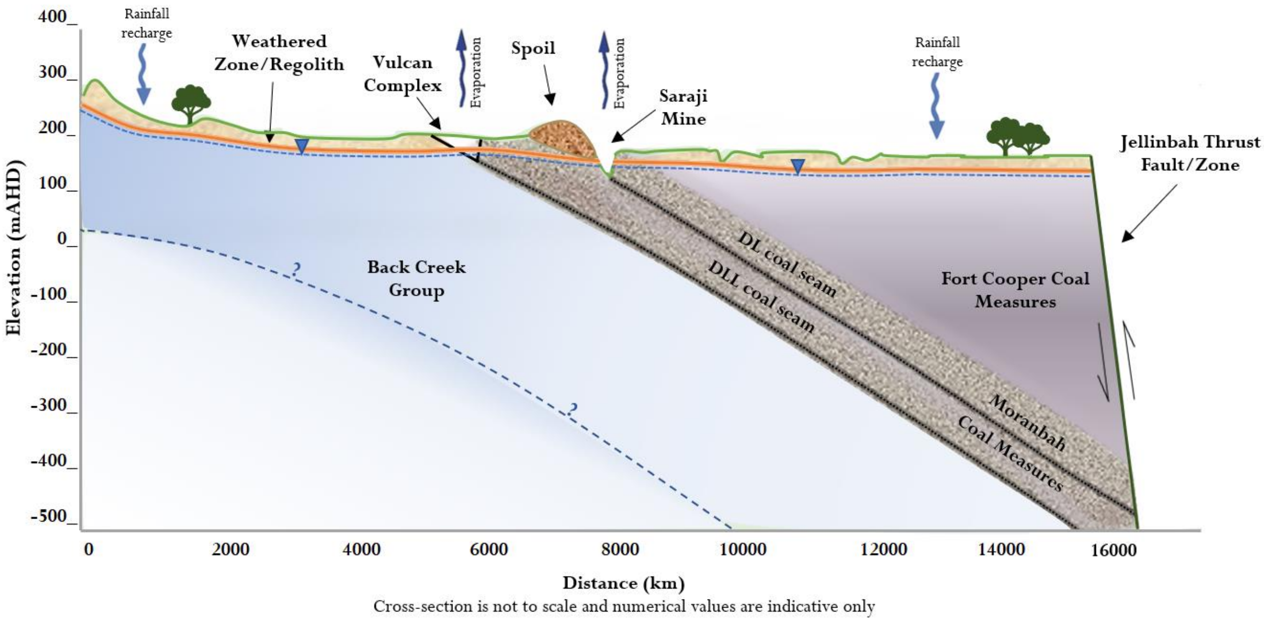


Figure 3.7 West to east conceptual hydrogeological cross-section

4. Hydrogeology

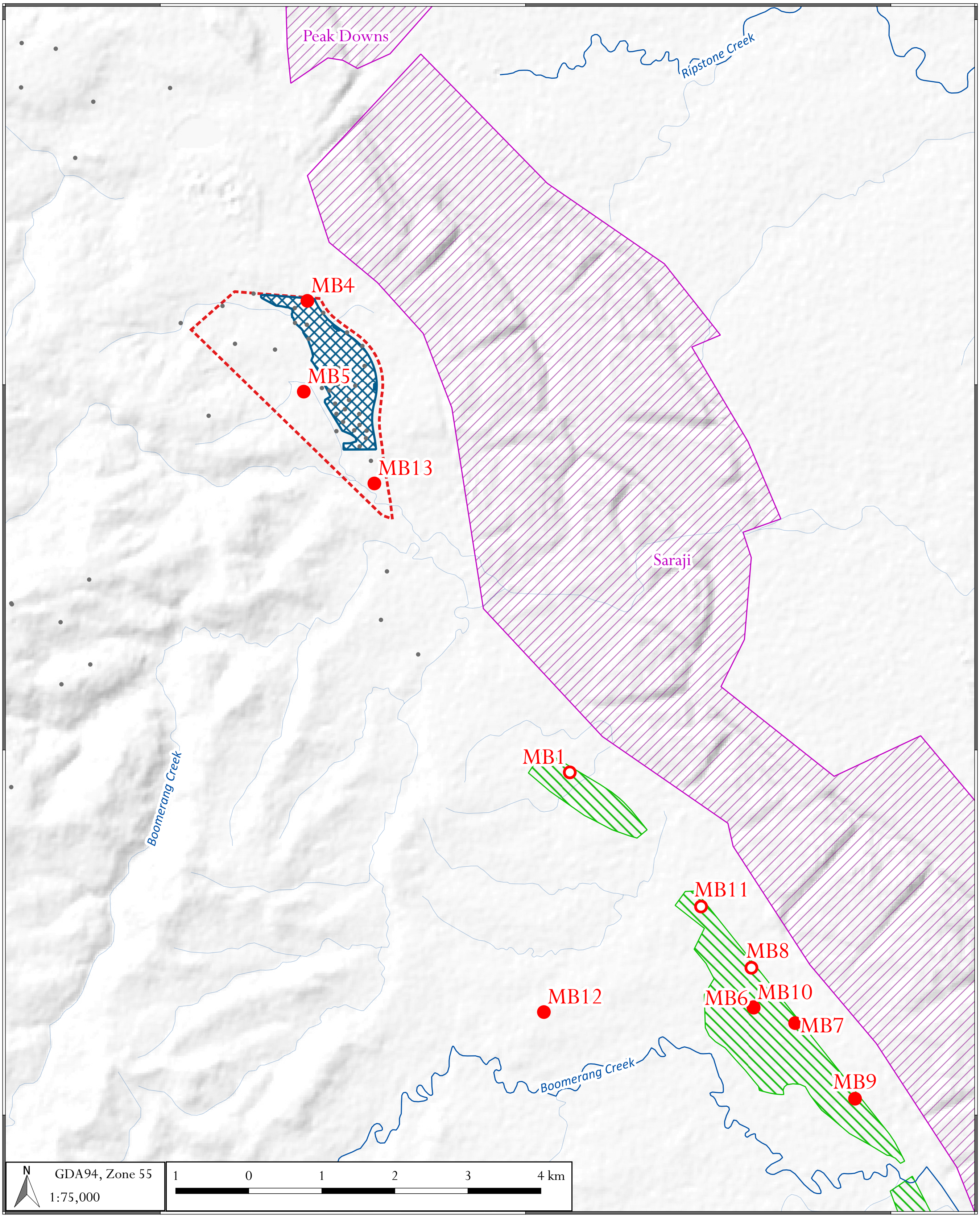
4.1. Existing monitoring network

In June 2019, twelve monitoring bores were drilled for the Vulcan Complex Project area (including current VCM footprint). Another bore, MB13, was drilled in February 2021. Table 4.1 summarises the location, target unit and construction details for each monitoring bore (hydrogeologist.com.au, 2019). The locations of the bores are shown in Figure 4.1.

A total of six monitoring bores were dry after drilling and construction indicating that these bores are constructed above the regional groundwater table. MB3 initially recorded a groundwater level after drilling, however the monitoring bore subsequently went dry and this initial value is thought to have been influenced by the introduction of drilling fluid during drilling. All monitoring bores were equipped with pressure transducers collecting automatic readings every four hours. Groundwater monitoring and sampling is regularly being carried out at the monitoring network to collect representative samples for baseline characterisation.

Table 4.1 Vulcan Complex Project monitoring bores

ID	Easting	Northing	Target unit	Casing height (maGL)	Hole depth (mbGL)	Screen interval (mbGL)	Airlift yield (L/min)	Casing elevation (mAHD)
MB1	625606	7529691	DLL coal seam	0.70	24.9	21.9 – 24.9	Dry	222.91
MB2	622513	7534483	DLL coal seam	0.71	12.0	9.0 – 12.0	Dry	254.69
MB3	622668	7535017	DLL coal seam	0.70	33.8	30.8 – 33.8	<0.1	257.68
MB4	622014	7536148	DLL coal seam	0.71	21.5	18.5 – 21.5	1	243.28
MB5	621964	7534905	MAT coal seam	0.77	40.9	37.9 – 40.9	0.5	252.70
MB6	628119	7526476	Weathered Permian	0.70	24.6	21.6 – 24.6	Dry	214.61
MB7	628691	7526258	Weathered Permian	0.67	43.0	40.0 – 43.0	0.1	215.99
MB8	628092	7527015	Weathered Permian	0.70	24.0	21.0 – 24.0	Dry	212.24
MB9	629511	7525222	DLL coal seam	0.65	34.4	31.4 – 34.4	0.1	208.98
MB10	628123	7526469	DLL coal seam	0.70	40.3	37.3 – 40.3	<0.1	214.60
MB11	627403	7527854	DLL coal seam	0.70	29.9	26.9 – 29.9	Dry	225.66
MB12	625251	7526409	Back Creek Group	0.66	38.2	32.2 – 38.2	1	241.43
MB13	622931	7533648	MAT coal seam	0.63	36.92	33.5 – 36.5	Unknown	223.13



LEGEND

- Vulcan ML 700060
- Vitrinite VCM Pit
- Proposed Vulcan Mine Extension
- Adjacent mining project
- Existing exploration hole
- Existing monitoring bore
- Existing monitoring bore - dry

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Existing monitoring network

FIGURE No.
4.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.

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4.2. Water levels

The manual groundwater level measurements collected at the site are summarised in Table 4.2. The groundwater table elevations are generally between 230 mAHD and 240 mAHD within the VCM and between 180 mAHD and 220 mAHD further to the south. The depth to groundwater measurements indicate that, except for MB4, the depth to groundwater is between 14 m to 37 m below ground level.

Figure 4.2 shows the groundwater elevation hydrographs at the six monitoring bores (note that the hydrographs for MB4 and MB5 overlap) from June 2019 through to September 2021. Except for the spikes in data observed at MB4, MB5, MB12 and MB13, the groundwater elevation hydrographs demonstrate a static system with very little (~centimetre magnitude) variation in groundwater level. The notable spikes in the data are associated with the groundwater sampling events. The bores with the spikes (MB4, MB5, MB12 and MB13) are constructed within low hydraulic conductivity formations and the groundwater is slow to recover following purging.

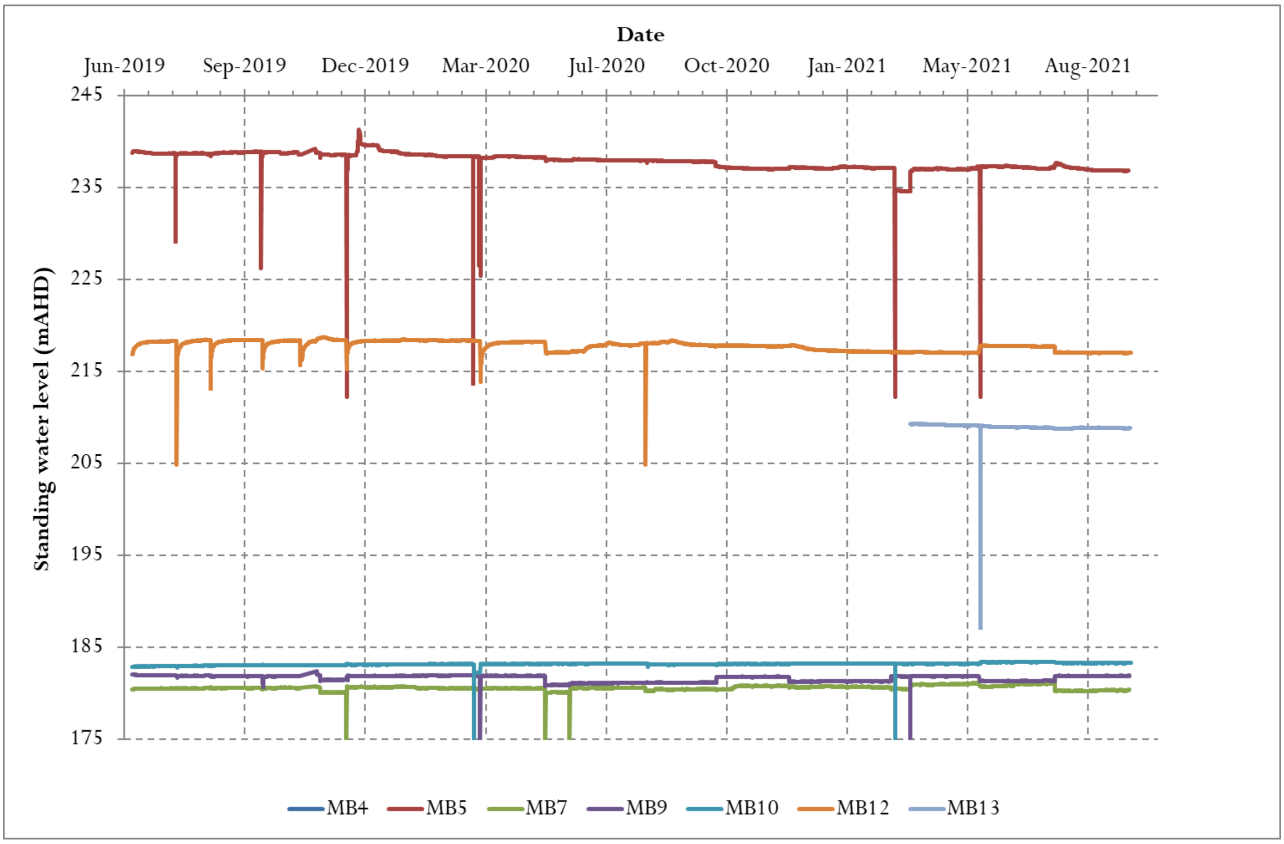


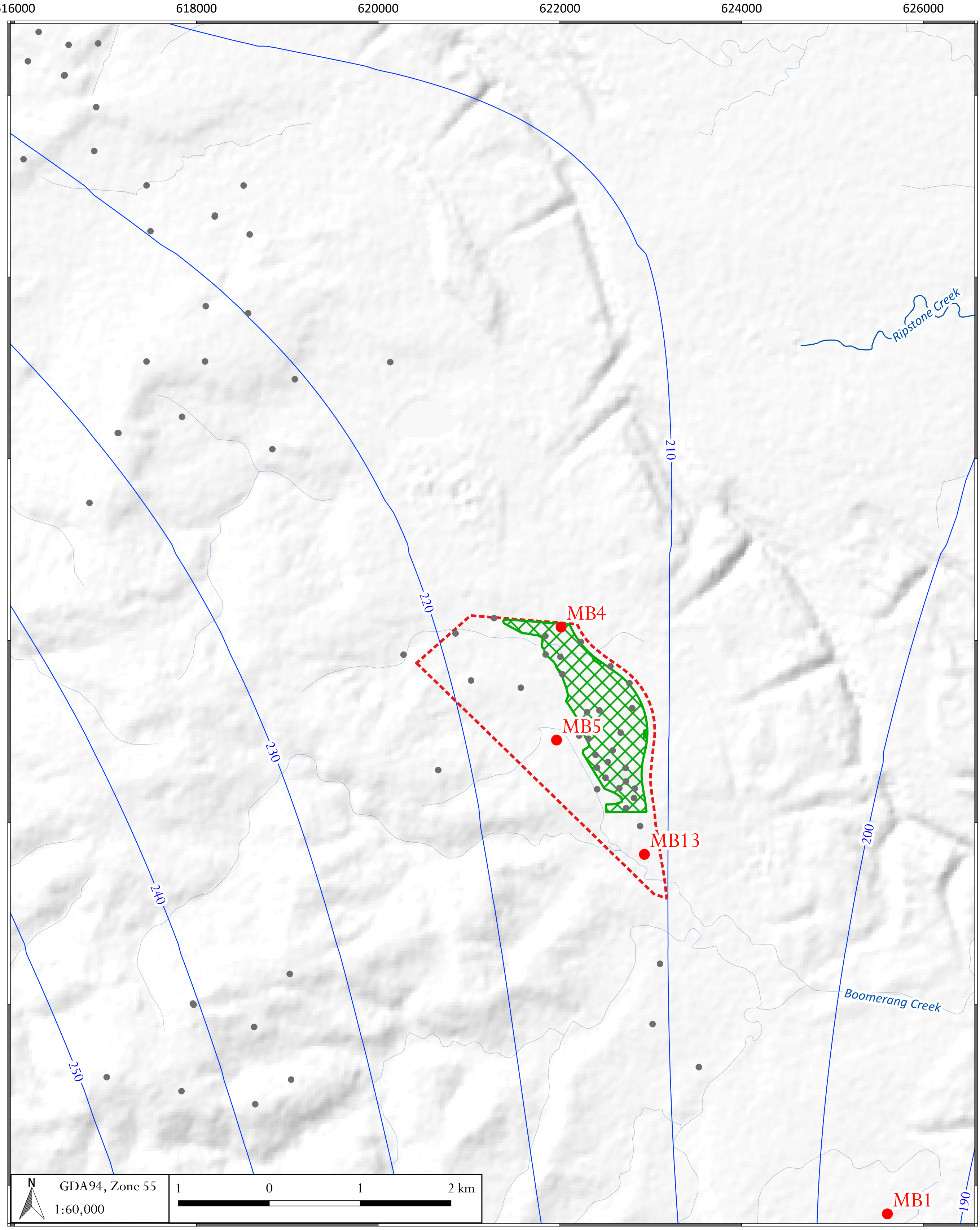
Figure 4.2 Groundwater hydrographs for Vulcan Complex Project monitoring bore

Table 4.2 Summary of manual groundwater elevation measurements (mAHD)

Site ID	Casing elevation (mAHD)	SWL														
		Jun 2019	Jul 2020	Aug 2019	Sep 2020	Oct 2019	Dec 2019	Mar 2020	Jun 2020	Aug 2020	Oct 2020	Dec 2020	Mar 2021	May 2021	Jul 2021	Sep 2021
MB1	222.91	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB2	254.69	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB3	257.68	239.38	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB4	243.28	237.47	237.58	237.45	237.18	237.75	238.13	237.53	237.53	236.76	236.54	236.37	236.58	236.61	236.53	236.41
MB5	252.70	238.17	238.01	237.99	238.23	238.69	238.55	238.10	227.77	235.95	236.62	236.53	236.37	236.72	236.41	236.04
MB6	214.61	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB7	215.99	181.19	179.71	179.77	179.79	180.31	180.12	180.40	189.79	179.92	179.87	179.91	179.99	179.91	179.96	180.03
MB8	212.24	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB9	208.98	181.57	181.34	181.36	181.39	181.81	181.48	182.12	181.88	181.24	180.98	181.29	181.35	181.33	181.32	181.43
MB10	214.60	182.09	182.15	182.20	182.29	183.04	183.00	183.04	188.10	182.49	182.50	182.55	182.60	182.56	182.61	182.65
MB11	225.66	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB12	241.43	215.36	216.22	216.41	216.66	218.00	218.39	216.94	215.71	216.55	216.56	216.53	215.85	215.60	215.61	214.85
MB13	223.13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	209.12	208.53	208.49	208.63

4.2.1. Flow directions

Figure 4.3 shows composite regional groundwater elevation contours (groundwater elevations from different times and from various hydro-stratigraphic units), based on 313 individual datapoints collated from the Groundwater Database (Department of Natural Resources, Mines and Energy, 2019), site specific monitoring bores and project exploration drill holes and groundwater elevations summarised as part of neighbouring projects. The contours presented in Figure 4.3 clearly indicate regional groundwater flow to the east near the VCM.



LEGEND

- Vulcan ML 700060
- Vitrinite VCM Pit
- Existing monitoring bore (MB)
- Existing exploration hole (VSW)
- Composite regional SWL contour (mAHD)

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Underground Water Monitoring Plan – Vulcan Coal Mine

Composite groundwater elevation contours

FIGURE No.
4.3

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.

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4.3. Water quality

The groundwater quality within the VCM was assessed on field indicators (total dissolved solids [TDS], electrical conductivity [EC] and pH) as well as major ion analysis and analysis of dissolved metals.

4.3.1. Salinity

TDS is a non-specific, quantitative measure of the amount of dissolved inorganic chemicals (sum of the cations and anions) and is used as a broad indicator of an array of chemical contaminants. As the dissolved inorganic chemicals are mostly in the form of salts, the term 'salinity' is often used to describe the overall content of dissolved inorganic material. The amount of dissolved material also strongly correlates with EC, and either of the values can be used to estimate the other with high degree of accuracy. Based on the salinity of groundwater, the potential use of the water can be summarised as follows (Table 4.3).

Table 4.3 Groundwater salinity classification based on Mayer *et.al.* (2005)

Salinity status	EC* (µS/cm)	Description and use
Fresh	<750	Drinking and all irrigation
Marginal	750 – 1,500	Most irrigation, adverse effects on ecosystems become apparent
Brackish	1,500 – 3,000	Irrigation certain crops only; useful for most stock
Saline	3,000 – 15,000	Useful for most livestock
Highly saline	15,000–52,000	Very saline groundwater, limited use for certain livestock
Brine	>52,000	Seawater; some mining and industrial uses exist

Notes: **converted from total dissolved solids (TDS in mg/L) using a conversion factor of 0.67; rounded values*
http://www.water.wa.gov.au/water-topics/water-quality/managing-water-quality/understanding-salinity

The EC of groundwater samples falls between brackish – 2,280 µS/cm (MB4, representing DLL related groundwater, measured June 2019) and highly saline – 23,500 µS/cm (MB12, representing underlying Back Creek Group sediments, sampled December 2020). The average EC value generally increases with depth, from ~5,000 µS/cm in the surficial weathered profile through to ~7,300 µS/cm in the Permian coal seams (both MAT and DLL) to ~20,400 µS/cm in the underlying Back Creek Group. The statistical summary of EC values for individual hydrostratigraphic units is presented in Table 4.4 and Figure 4.4.

Table 4.4 Summary of EC measurements

Bores		EC (µS/cm)			
		n	Minimum	Mean	Maximum
Weathered zone	MB7	14	5,150	5,485	5,890
DLL	MB4, MB9, MB10	44	2,280	9197	16,200
MAT	MB5, MB13	20	2,400	3,014	4,100
Back Creek Group	MB12	15	14,800	20,360	23,500
All observations		93	2,280	9,109	23,500

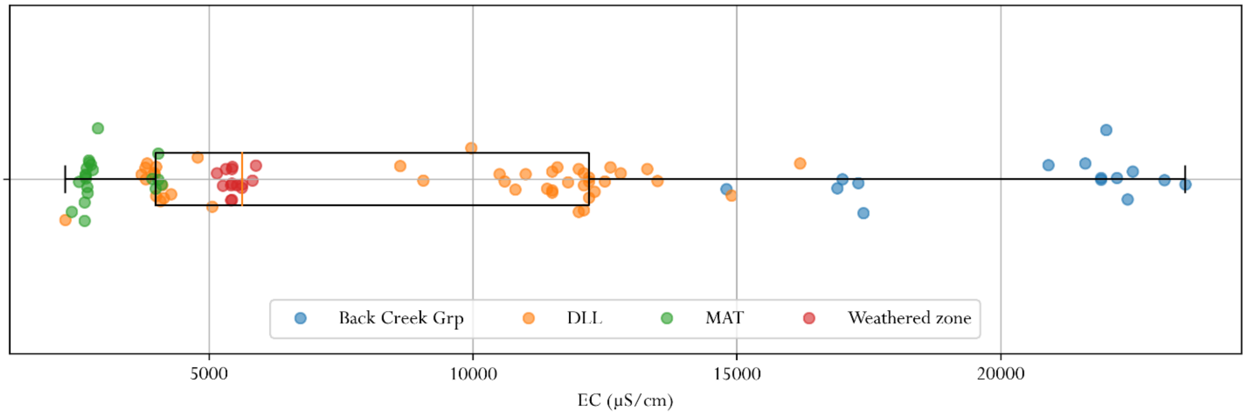


Figure 4.4 Distribution of EC values

In terms of observed changes of EC in time (Figure 4.5), for most of the monitoring bores, the variability seen in the early sampling events has plateaued out. This is particularly evident in MB4, where the initial increase in EC has stabilised over time. The highest degree of variability is seen in MB12 (screened within the Back Creek Group).

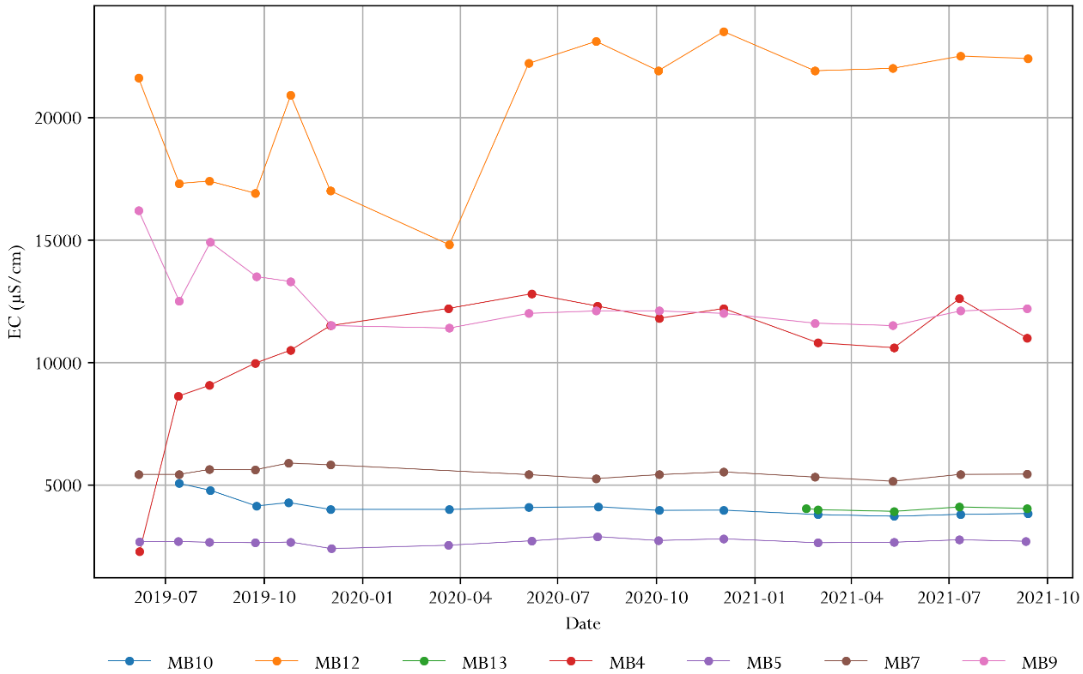


Figure 4.5 Change of EC values over time

4.3.2. Acidity (pH)

pH is defined by the "activity of hydrogen ion (H^+)" and controls solubility and concentrations of elements in water. For example, many metals precipitate out of alkaline water, whereas many metals dissolve in acidic water. In the context of mining, increased pH (increased acidity) is often associated with acid rock drainage, a process during which surface water seeps through unsaturated spoil or bedrock. The seepage then becomes acidic and leaches various contaminants (dissolved metals such as copper or iron) out of the spoil.

The Vulcan Complex Project related values of pH are summarised in Table 4.5 and graphically presented in Figure 4.6 and Figure 4.7. After an initial period of stabilisation between June and August 2019, the pH of the monitoring bores have been relatively stable, with the exception of MB4 which didn't appear to stabilise until November 2019 at pH of ~5.5. However, from August 2020, pH values in all bores started to fluctuate but generally increase over time. By September 2021, pH of MB4 was slightly over 6.0 and the rest of the samples are neutral to slightly alkaline with pH between 7.9 and 8.2 (average 8.1).

Table 4.5 Summary of pH measurements

Bores		pH (-)			
		n	Minimum	Mean	Maximum
Weathered zone	MB7	14	7.3	7.7	8.3
DLL	MB4, MB9, MB10	44	5.2	7.1	8.2
MAT	MB5, MB13	20	7.4	7.8	8.2
Back Creek Group	MB12	15	7.1	7.5	7.9
All observations		93	5.2	7.4	8.3

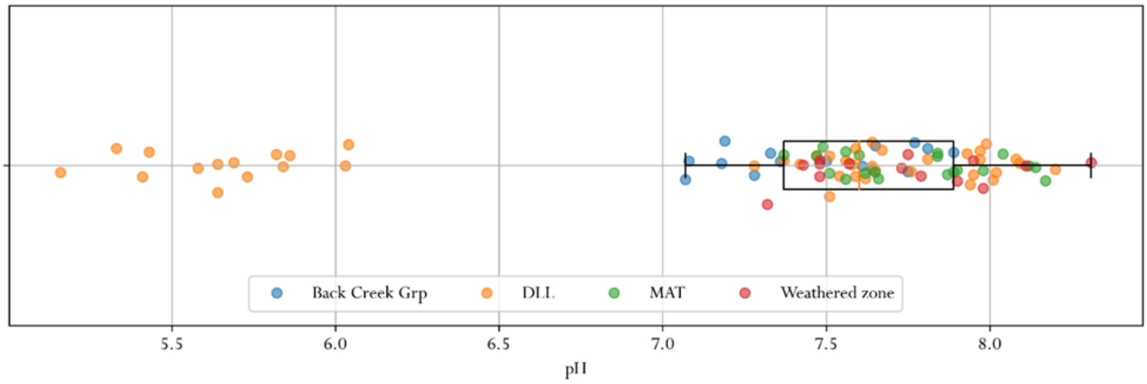


Figure 4.6 Distribution of pH values

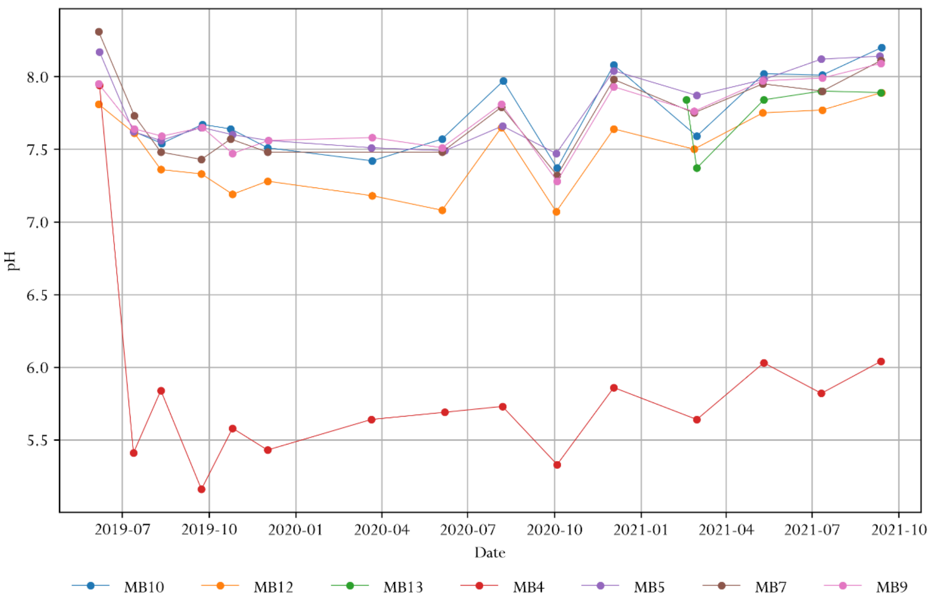


Figure 4.7 Change of pH values over time

4.3.3. Major ion analysis

The major ion analysis uses graphical means (charts and diagrams) to describe water quality and characterise the types of groundwater based on the ratios of major cations (Na^+, K^+, Ca^{2+}, $Mg^2$and anions (Cl^-, $SO4^{2-}$, $CO_3^{2-}$and HCO_3^-).

The Piper diagram presenting all 93 groundwater samples (Figure 4.8) indicates that most of the Vulcan Complex Project groundwaters are strongly dominated by sodium (Na) and moderate to strongly dominated by chloride (Cl). All VCM specific groundwaters would fall into the sodic waters of marine origin category of Raymond and McNeil (2011). Chloride, as a percentage of anions, varies between 40 % and 100%; however, some samples (MB5, MB10 and MB7 and MB13) indicate the presence of moderate bicarbonate (HCO_3). There does not appear to be a simple relationship between the hydro-stratigraphic unit and groundwater quality. For example, the markers for MB5, the deepest sampled coal seam (MAT) are indicating the lowest salinity and chloride percentage, contrary to the general observations made by URS (2012) and Arrow Energy (2016) indicating increase in salinity with increasing depth.

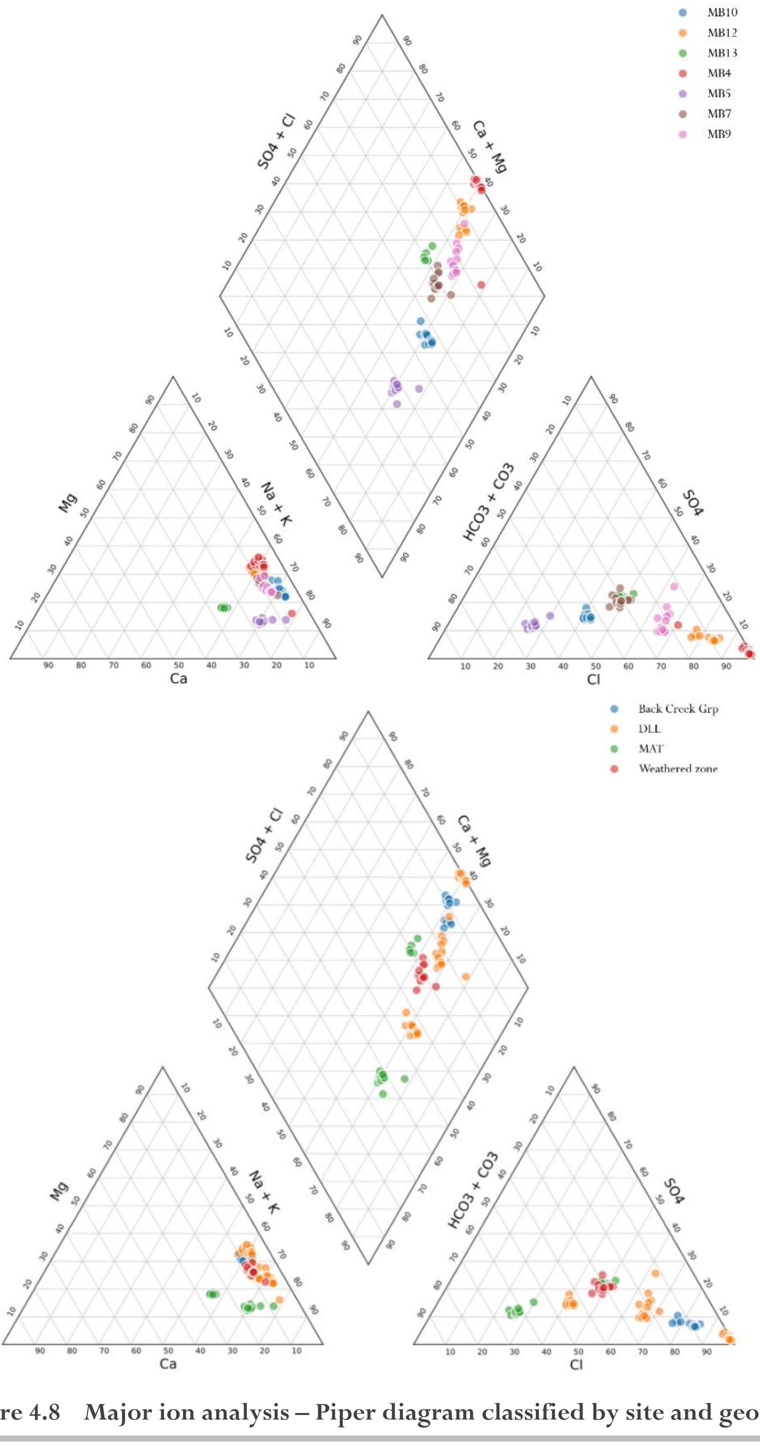


Figure 4.8 Major ion analysis – Piper diagram classified by site and geology

4.3.4. Sulfate (SO_4)

Sulfur (S) occurs in nature as in its pure atomic form or it combines with other elements to form sulfides (S^{2-}) and sulfates (SO_4^{2-}). While sulfides in nature are mostly insoluble in water (many important ores are sulfide minerals), they readily oxidise to water-soluble sulfates during natural weathering processes. The resulting sulfate salts then can be leached from shallow weathered profile by runoff and shallow seepage and accumulate in groundwater or surface water.

The coal mining process facilitates the weathering (and potential formation of soluble sulfates) of large amounts of rock by disturbing the bedrock and generating 'spoil' or waste rock. The large quantities of mechanically disturbed rock of various origin are exposed to air (facilitating weathering - oxidation) and water (in the form of rainfall recharge or surface water seepage). If sulfide minerals (such as pyrite) are present in the spoil, acid rock drainage may occur.

The statistics and distribution of sulfate ion concentrations in the Vulcan Complex Project groundwater samples are summarised in Table 4.6 and Figure 4.9. Samples from DLL have a wide range of concentration, between the minimum of 99 mg/L to the maximum of 2580 mg/L. Figure 4.10 shows the development of sulfate over time, generally flat with exception of MB9 (DLL), which originally had a sulfate concentration of ~2,600 mg/L and gradually decreased to ~750 mg/L. As of the latest (September 2021) sampling round, the sulfate concentration in all bores have stabilised with the values varying from ~100 mg/L (MB4, DLL) to ~820 mg/L (MB12, Back Creek Group).

Table 4.6 Summary of SO_4 measurements

Bores		SO_4 (mg/L)			
		n	Minimum	Mean	Maximum
Weathered zone	MB7	14	592	704	819
DLL	MB4, MB9, MB10	44	99	537	2,580
MAT	MB5, MB13	20	196	331	579
Back Creek Group	MB12	15	682	844	1,090
All observations		93	99	567	2,580

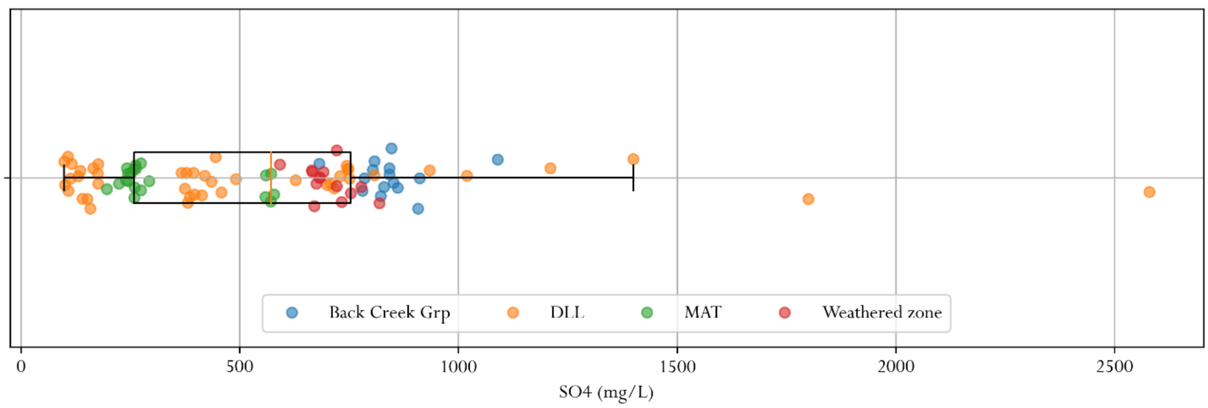


Figure 4.9 Distribution of SO_4 values

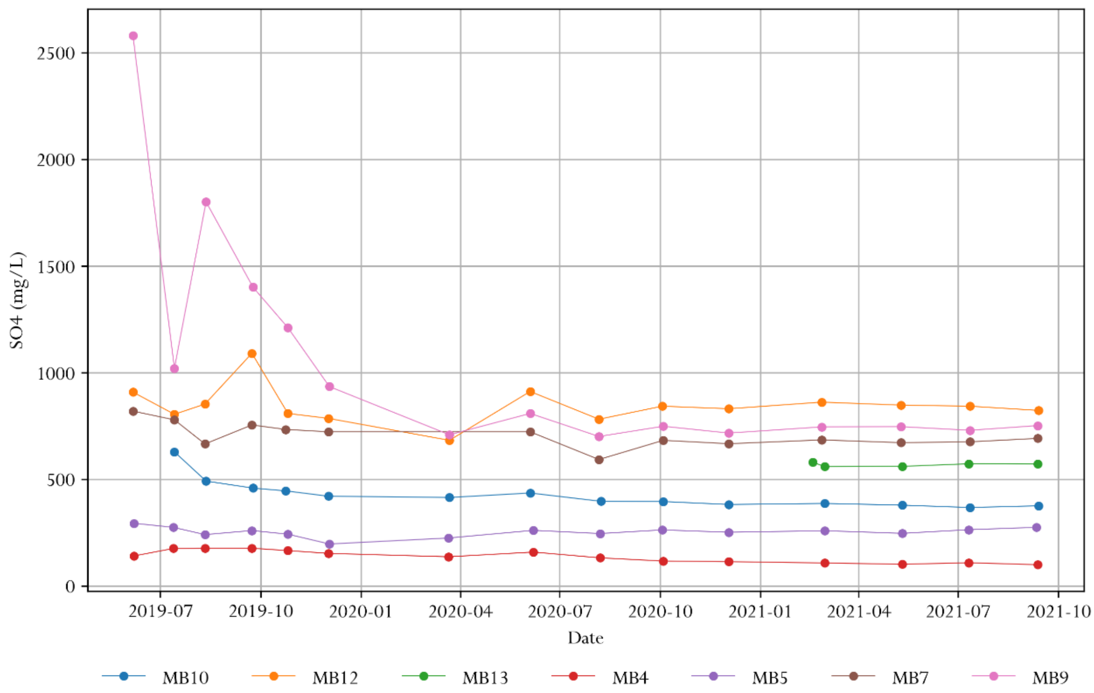


Figure 4.10 Development of SO_4 values over time

4.3.5. Iron (Fe)

Iron is the second most abundant metal and fourth most common element in the earth's crust. In the natural setting, it is most commonly found in the form of its oxides (such as hematite, magnetite), sulphides (pyrite, marcasite), hydroxides (goethite) and carbonates (siderite).

In higher concentrations, dissolved iron (Fe^{2+}) in water is unstable and often precipitates in the form of ferric (Fe^{3+}) oxyhydroxide – rust. Elevated concentration of iron in combination with anaerobic conditions also promotes bacterial growth in groundwater or surface water environments. In the context of mining, increased concentrations of dissolved iron (together with increased concentration of sulfate ions) can be indicator of weathering of sulfide minerals (pyrite) – see Section 4.3.4.

The concentration of dissolved iron in groundwater samples from the Vulcan Complex Project is generally low, with 22 measurements below detection limit (LOR – 0.05 mg/L). Out of 71 measurements above LOR, samples from site MB4 clearly stand out (Figure 4.11, Figure 4.12) as the dissolved iron content on this site (on average 192.4 mg/L) is more than two orders of magnitude higher than in the rest of the samples (average of 0.96 mg/L). The Fe^{2+} concentration in MB4 samples does not appear to have stabilised over the observation period, increasing from 0.36 mg/L during the first sampling round (on June 2019) to 271 mg/L in March 2020, before decreasing since (Figure 4.12).

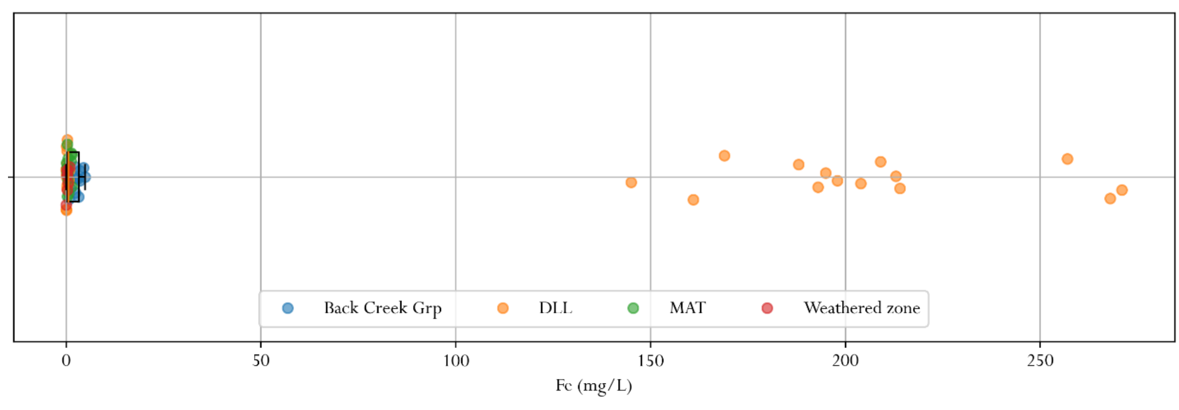
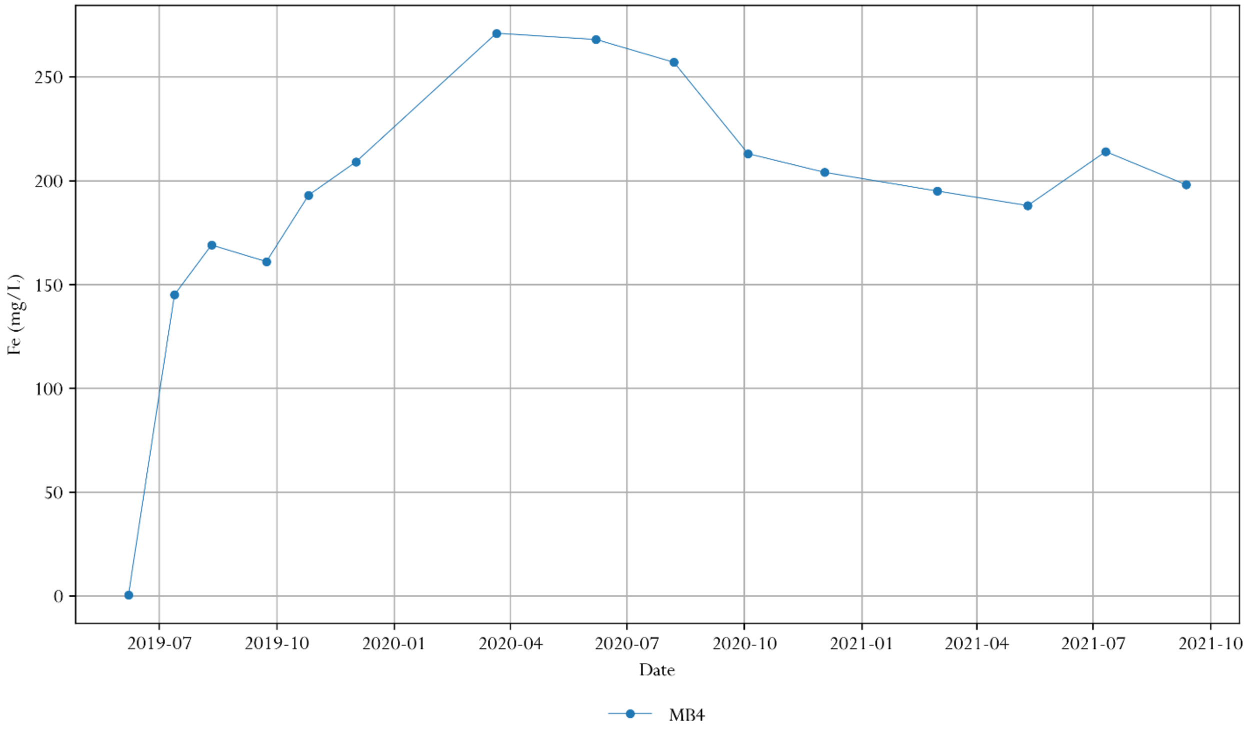


Figure 4.11 Distribution of Fe concentration values



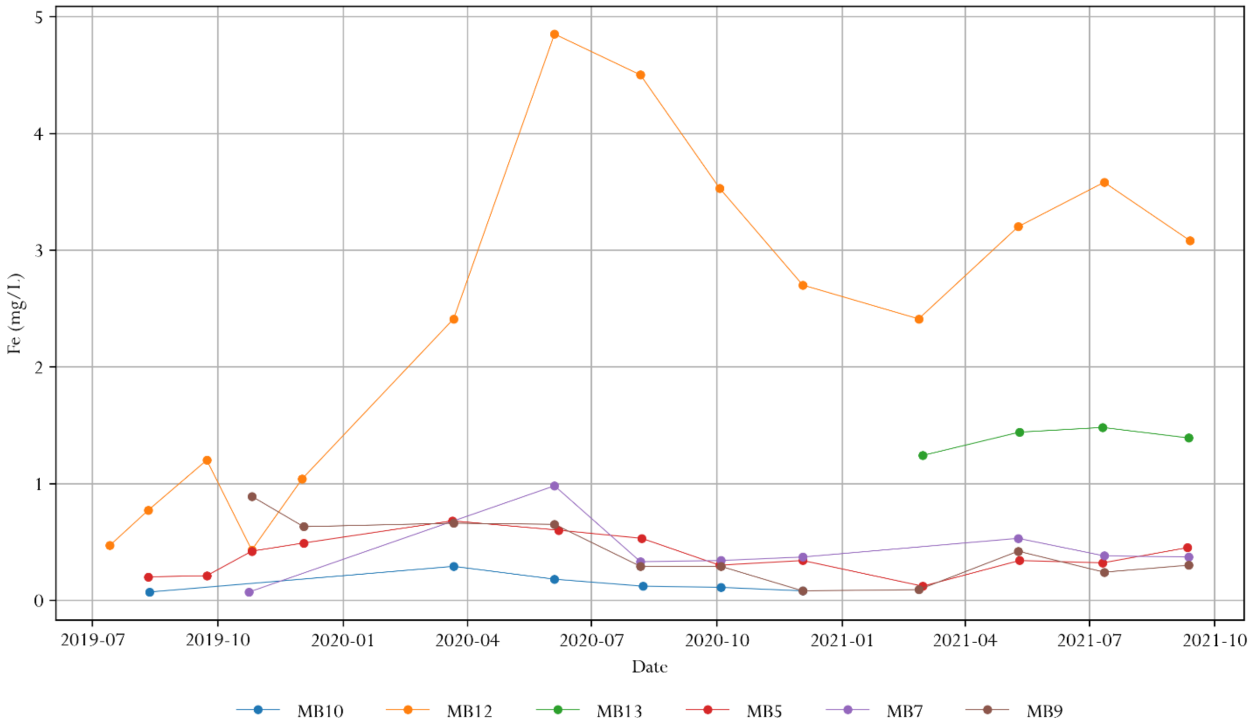


Figure 4.12 Development of Fe concentration values over time

4.3.6. Aluminium (Al)

Aluminium is the most abundant metallic element and constitutes about 8% of Earth's crust. It occurs naturally in the environment in the form of silicates (feldspars), oxides (corundum or its crystalline gem forms like ruby or sapphire) and hydroxides (gibbsite, a major component of aluminium ore - bauxite), combined with other elements, such as sodium and fluoride, and as complexes with organic matter (Fawell, 2010).

Aluminium is most commonly released to the environment by weathering of feldspars (plagioclase, orthoclase) or clay minerals (such as kaolinite, serpentinite or mica). Factors influencing aluminium mobility and subsequent transport within the environment are chemical speciation, hydrological flow paths, soil–water interactions and the composition of the underlying geological materials (Fawell, 2010).

Acidic environments can cause an increase in the dissolved aluminium content of the surrounding waters. The chemistry of aluminium in water is complex, and many chemical parameters, including pH, determine which aluminium species are present in aqueous solutions. In pure water, aluminium has a minimum solubility in the pH range 5.5 to 6.0; concentrations of total dissolved aluminium increase at higher and lower pH values (Fawell, 2010).

Concentration of dissolved aluminium in the Vulcan Complex Project groundwater samples is low, out of 93 samples, 82 had concentrations below limit of reporting (LOR – 0.01 mg/L) with average concentration of 0.03 mg/L in remaining 11 samples (Figure 4.13). The highest concentration of 0.08 mg/L was observed in the MB12 (Back Creek Group) sample from 4/6/2020 and MB4 (DLL) sample from 3/12/2020.

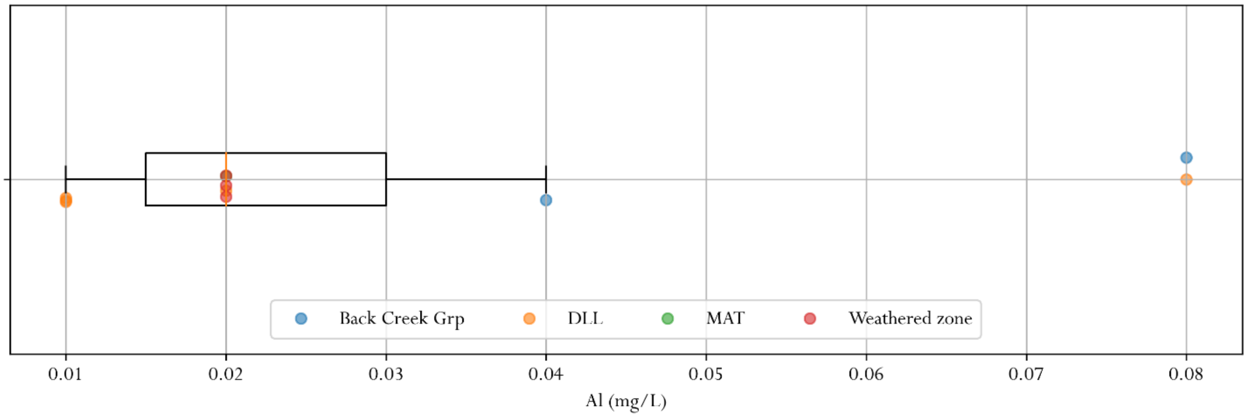


Figure 4.13 Distribution of Al concentration

4.3.7. Arsenic (As)

Arsenic is a metalloid widely distributed throughout Earth's crust, most often as arsenic sulfide or as metal arsenates (As^{5+}) and arsenides (As^{3+}). Arsenic is introduced into water through the dissolution of rocks, minerals and ores, from industrial effluents (including mining wastes), and via atmospheric deposition. In well oxygenated surface waters, arsenate (As^{5+}) is generally the most common arsenic species present; under reducing conditions, such as those often found in deep lake sediments or groundwater, the predominant form is arsenide (As^{3+}) (Fawell & Mascarenhas, 2011; M. F. Raisbeck et al., n.d.).

Concentration of arsenic found in groundwater samples collected at the Vulcan Complex Project site are low (Figure 4.14) with an average of 0.002 mg/L and maximum reported concentration of 0.009 mg/L (MB12, Back Creek Group, sampled on September 2019). Out of 93 samples, concentration of arsenic in 48 samples was evaluated as below limit of reporting (LOR – 0.001 mg/L).

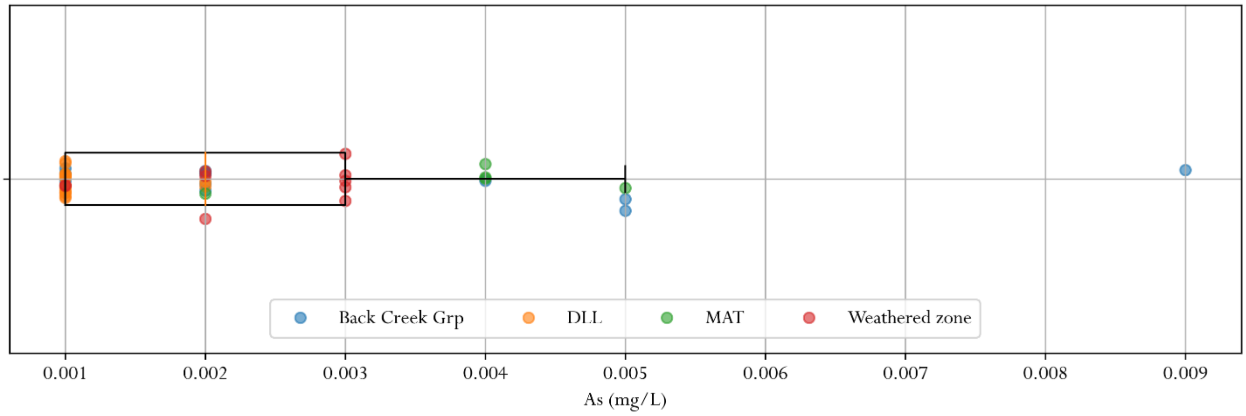


Figure 4.14 Distribution of As concentration

4.3.8. Mercury (Hg)

Mercury is naturally present in geologic deposits, soil, water, air, plants, and animals. Elemental mercury can readily volatilise and enter the atmosphere, where it can combine with other materials and settle. Natural sources of mercury include volcanoes, geologic deposits of mercury, volatilisation from the ocean, geothermal springs (CLU-IN, 2009) and forest fires. All 58 groundwater samples from the Vulcan Complex Project area showed concentration of dissolved mercury below detection limit (LOR – 0.0001 mg/L)

4.3.9. Molybdenum (Mo)

Molybdenum does not occur naturally as a free metal on Earth; it is found only in various oxidation states in water-insoluble minerals. Under natural conditions, molybdenum - together with other metals - forms oxides (such as wulfenite - $PbMoO_4$ or powellite - $CaMoO_4$) or sulfides such as molybdenite (MoS_2), the principal molybdenum ore. Molybdenum can also be recovered as a by-product of copper and tungsten mining. In the framework of coal mining activities, mine wastes have been identified as sources of molybdenum contamination (Frascoli & Hudson-Edwards, 2018).

The measured concentration of molybdenum in the groundwater samples associated with the Vulcan Complex Project (Figure 4.15 and Figure 4.16) are low. Out of 93 measurements, 50 were below detection limit (LOR – 0.001 mg/L). The average measurable concentration of molybdenum is 0.008 mg/L. However, samples from the new monitoring site MB13 had significantly higher concentration (average 0.05 mg/L) than the rest (average 0.0026 mg/L)

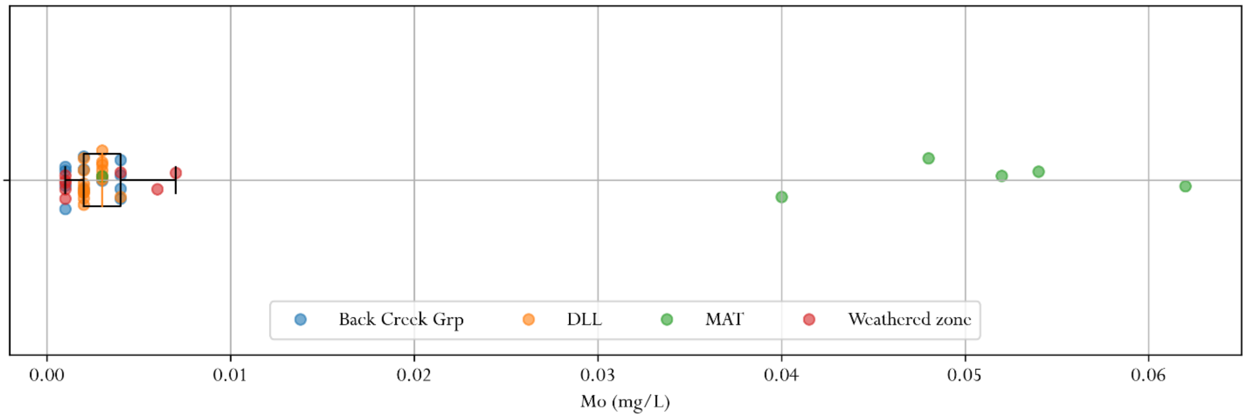


Figure 4.15 Distribution of Mo concentration

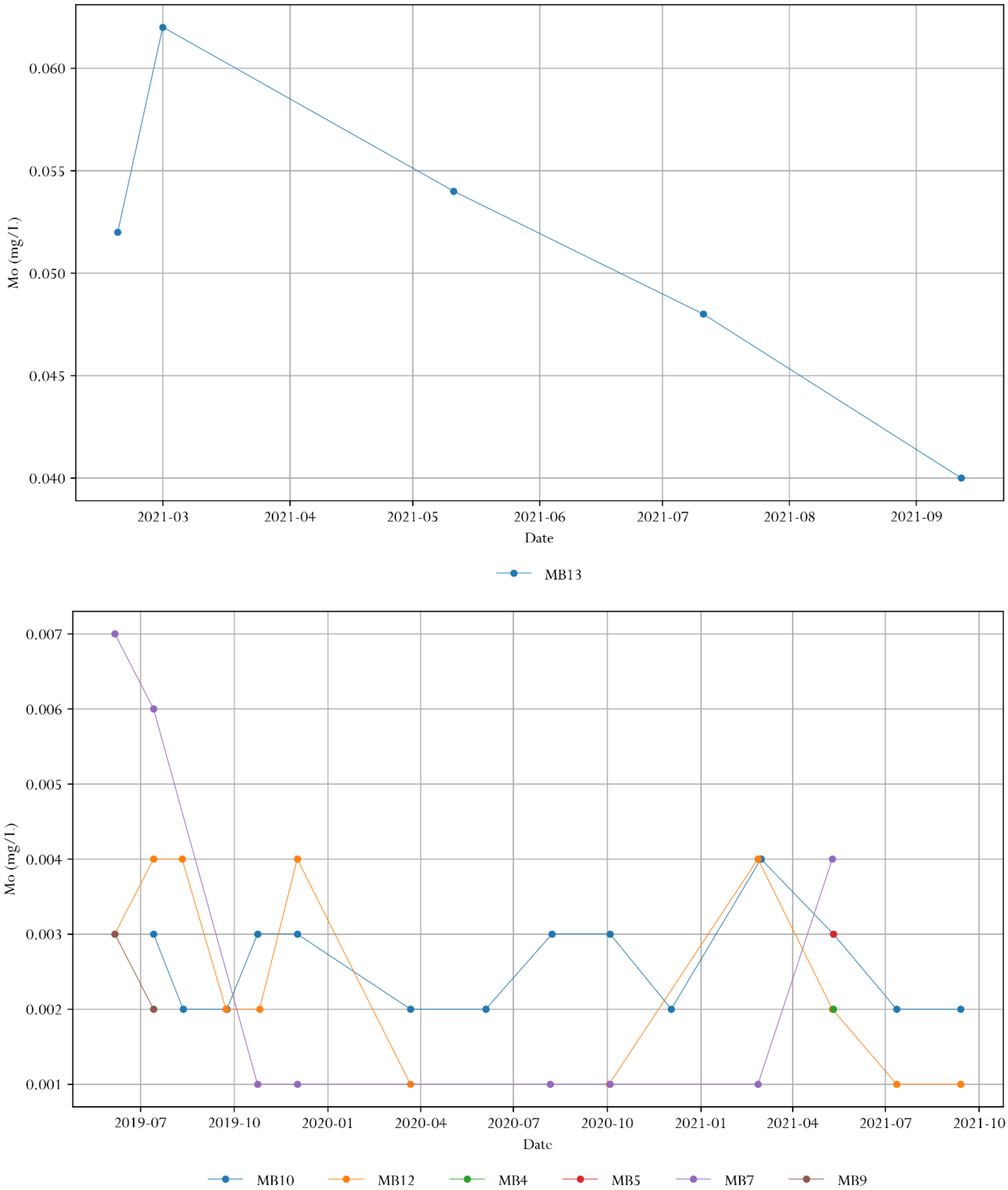


Figure 4.16 Development of Mo concentrations over time

4.3.10. Selenium (Se)

Selenium (Se) is present in the earth's crust, often in association with minerals containing sulfur. Higher concentrations of selenium can be associated with some volcanic, sedimentary and carbonate rocks. In the environment, selenium occurs in several forms, based on its oxidation states: selenides (Se^{2-}), amorphous or polymeric elemental selenium (Se^{0}), selenites (Se^{4+}) and selenates (Se^{6+}) (Fawell & Combs, 2011). Selenites (Se^{4+}) and selenates (Se^{6+}) are soluble in water.

Selenium contamination is associated with coal ash and coal mine wastes, especially in Appalachian region of United States (Norton et al., 2011), where various stakeholders documented impact of selenium contamination caused by runoff from overburden deposits on aquatic organisms.

All 93 groundwater samples from the Vulcan Complex Project area showed concentration of selenium below detection limit (LOR – 0.01 mg/L).

4.3.11. Total petroleum hydrocarbons (TPH)

Total petroleum hydrocarbons (TPH) is a term used to describe a large family of several hundred chemical compounds that originate from crude oil (ATSDR, 1999). Because there are so many different chemicals in crude oil and in other petroleum products, it is not practical to measure each one separately. However, it is useful to measure the total amount of TPH at a site.

TPH is not included in the VCM EA conditions.

4.3.12. Total recoverable hydrocarbons (TRH)

TRH (Total Recoverable Hydrocarbons) analysis can be used as a nonspecific quantitative screening tool to determine the quantity of organic compounds in a water sample, including petroleum hydrocarbons. The method is limited to those organic compounds that can be extracted by solvent (dichloromethane) and detected by GC-FID (gas chromatography-flame ionisation detector).

TRH C6-C9 and TRH C10-C36 are listed in the EA groundwater conditions (Table 2.1) with trigger level and contaminant limits (Table 5.2). Both TRH and TPH have been sampled since December 2020. All measurements are lower than LOR.

4.4. Environmental values

(Department of Environment and Heritage Protection, 2011) defines environmental values (EVs) for water as qualities of water that make it suitable for supporting aquatic ecosystems and human water uses. These EVs need to be protected from the effects of habitat alteration, waste releases, contaminated runoff and changed flows to ensure healthy aquatic ecosystems and waterways that are safe for community use. The EVs specific for the VCM are defined in the *Isaac River Sub-basin Environmental Values and Water Quality Objectives* document (Department of Environment and Heritage Protection, 2011) for following areas:

- aquatic ecosystems;
- irrigation;
- farm supply/use;
- stock water;
- primary recreation;
- drinking water; and
- cultural and spiritual.

Given the number of coal mines operating in the catchment, industrial use of groundwater was also evaluated, although not part of official values listed in the *Isaac River Sub-basin Environmental Values and Water Quality Objectives* document.

4.4.1. Aquatic ecosystems

The water quality objective (WQO) for aquatic ecosystems, where groundwaters interact with surface waters, is that groundwater quality should not compromise the identified EVs for those waters. Given the levels of salinity in VCM groundwaters (the groundwater is classified as brackish to extremely saline – see Section 4.3.1), and lack of natural groundwater-surface water interaction, the VCM groundwaters are not suitable to support fresh- or marginal aquatic ecosystems.

4.4.2. Farm use / irrigation

The water quality objective (WQO) for pathogens and metals are provided in Tables 8 and 9 of the *Isaac River Sub-basin Environmental Values and Water Quality Objectives* document (Department of Environment and Heritage Protection, 2011), indicators other than pathogens and metals are discussed in *Australian and New Zealand guidelines for fresh and marine water quality* (ANZECC & ARMCANZ, 2018).

The VCM groundwaters are again mostly outside of the accepted salinity interval of EC values between 1,000 µS/cm and 7,300 µS/cm (ANZG 2018, Table 4.2.5). If the groundwater was to be used for irrigation purposes, high contents of salts (in combination with other factors) can cause soil degradation. The VCM groundwater is not suitable for farm use and/or irrigation.

4.4.3. Livestock watering

Authors of *Australian and New Zealand guidelines for fresh and marine water quality* (ANZECC & ARMCANZ, 2018, sec. 4.3.3.5) state that if stock is exposed to high salinity water for prolonged periods of time, loss of production and a decline in animal health occurs. For beef cattle, decline in health or loss of production may occur if the EC is between 7,463 µS/cm and 14,925 µS/cm.

Of the local groundwater, MB5, MB7, MB10 and MB13 have EC that is less than 7,463 µS/cm; MB4 and MB9 are between 7,463 µS/cm and 14,925 µS/cm. Groundwater at MB12 is greater than 14,925 µS/cm. The VCM groundwater can be considered as partially/potentially suitable for livestock watering purposes.

4.4.4. Primary recreation

This category of EVs is considered not applicable to local groundwater. There are no groundwater springs in the area of the VCM that could be considered for recreational use. This EV is more common for surface water features that are readily accessible for recreation.

4.4.5. Drinking water suitability

The site-specific groundwater quality data, as presented in Section 4.3, indicates that groundwater is unsuitable for human consumption before treatment primarily due to elevated levels of salts. Other indicators exceeding the recommended values are total hardness (recommended limit of 150 mg/L) and sodium (recommended limit of 30 mg/L).

4.4.6. Cultural and spiritual values

There are no groundwater springs or seeps that supply surface water bodies in the area of the VCM known to have significant indigenous and/or non-indigenous cultural heritage associations.

4.4.7. Industrial use

We understand that Vitrinite may intend to use some of the groundwater inflow to the proposed pits, if available after evaporation, for industrial purposes. It is understood that the nearest mine, Saraji Mine does not utilise groundwater for its operations.

No industrial users, other than mines, appear to be within close proximity of the Project area. The salinity of the groundwater would likely impede most industrial uses. The local brackish to highly saline groundwater, which may report to the proposed pits, can potentially have limited use on the mine site (such as dust suppression).

4.4.8. Summary

In summary, the evaluation of groundwater EVs in the VCM area indicates that groundwater in the "deep" hydrogeological units, associated with the regolith and/or Permian coal measures is of limited environmental value. The groundwater could be used for livestock beef cattle watering (limited); and for industrial purposes (limited to dust suppression) in mining.

4.5. Potential impact from mining activities

Open pit mining activities such as those proposed at the VCM may impact groundwater system in numerous ways. This groundwater monitoring plan (GWMP) is one part of the process of mitigating potential impacts by defining monitoring sites and processes so that any of these impacts can be assessed as they occur. Some of the understood coal-mining groundwater related impacts are (Jhariya et al., 2016; Tiwary, 2001):

- drainage of usable water from shallow aquifers;
- lowering of water levels in adjacent areas and changes in flow direction within aquifers;
- contamination of usable aquifers below mining operations due to infiltration (percolation) of poor-quality mine water; and
- increased infiltration of precipitation on spoil piles.

The increased infiltration may in turn result in:

- increased runoff of poor-quality water and erosion from spoil piles;
- recharge of poor-quality water to shallow groundwater aquifers; and
- poor-quality water flow to nearby streams.

Based on our conceptual understanding of the VCM and from numerical model predictions, the likely predicted impacts on the groundwater system due to the VCM are limited. The VCM site conditions, especially the unsaturated nature of shallow weathered profile and target coal seam (DLL), mean that:

- drainage of usable water from shallow aquifers will be non-existent or minimal (pit inflows will be very low); and
- there will likely be only negligible changes of flow direction in shallow aquifers.

The depressurisation and drawdown within the Permian will be limited in extent, and the magnitude of drawdown will be restricted by the depth of coal excavation.

The coal seam and bedrock water (see Section 4.3) is classified as brackish to highly to saline and downwards infiltration of mine waters into the groundwater would unlikely impact the groundwater quality in terms of salinity. The infiltration of precipitation through spoil (and potential runoff from spoil) is going to be limited by spoil rehabilitation and surface water management infrastructure and is expected to be negligible.

No mitigation strategies are currently proposed given the low probability of impact to the groundwater system.

5. Groundwater monitoring plan

The GWMP includes the measurement of groundwater levels (manual observations and data loggers) and groundwater quality (field and laboratory analyses). It is important to note that the GWMP is not designed to determine the impacts of the development on the groundwater quality and levels in the groundwater system surrounding the VCM, it is designed to provide guidance on monitoring locations and methodology.

The GWMP satisfies the general requirements of the guidelines below:

- Monitoring and Sampling Manual: Environmental Protection (Water) Policy. Brisbane: Department of Environment and Science (DES, 2018);
- Using monitoring data to assess groundwater quality and potential environmental impacts; Version 2 (Department of Environment and Science - DES, 2021);
- AS/NZ 5667 11 1998 - Water quality sampling. Part 11, guidance on sampling of groundwater (Standards Association of Australia & Standards New Zealand, 1998); and
- Australian Governments Groundwater Sampling and Analysis – A Field Guide (2009:27).

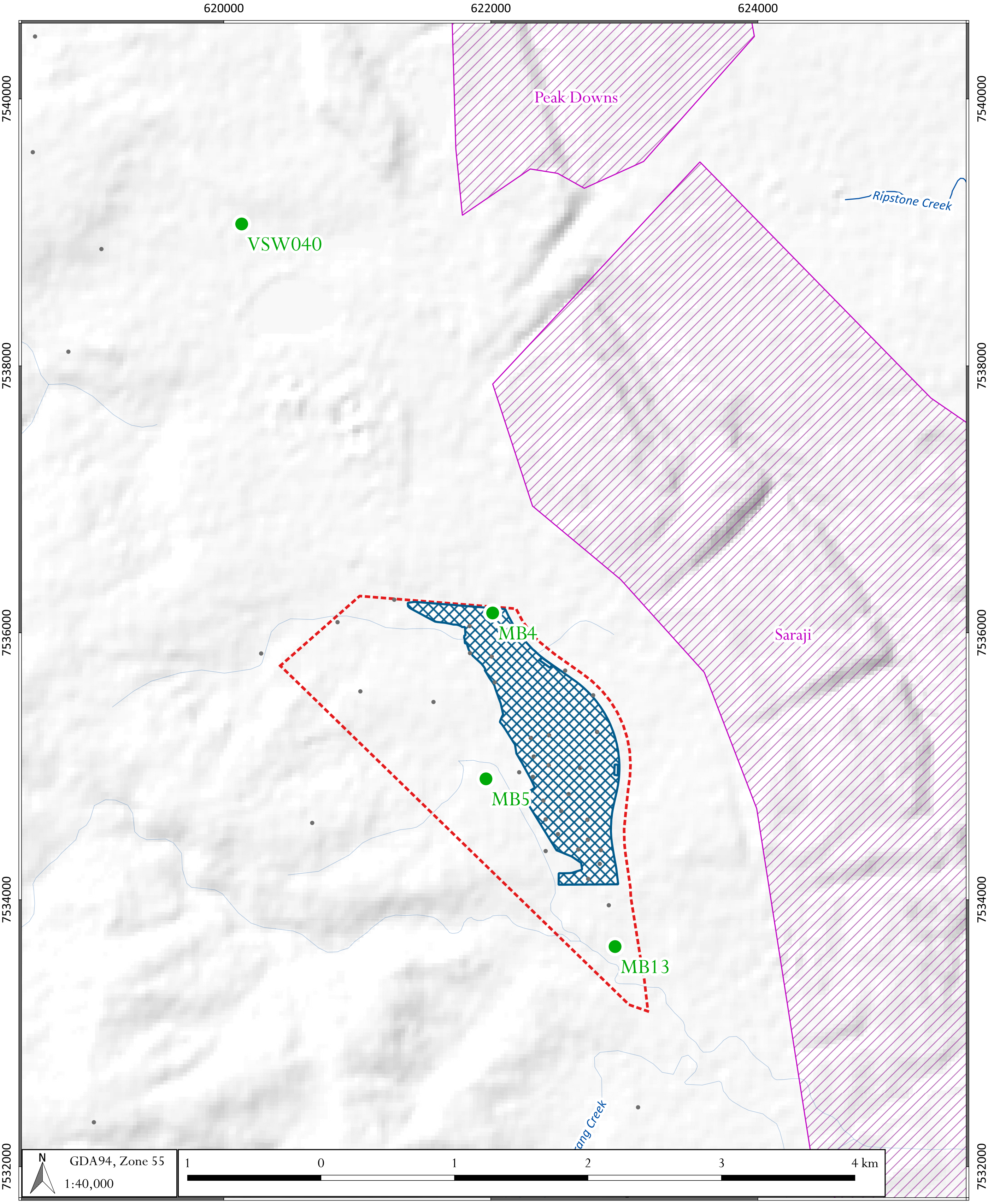
5.1. Groundwater monitoring network

The VCM groundwater monitoring network is designed around three considerations:

1. There is an existing monitoring network designed to observe water levels, water quality and hydrochemistry to provide baseline information for the proposed Vulcan Complex Project (see Sections 4.2 and 4.3).
2. The EA (EA0002912) proposes three bores from the existing monitoring network (MB04, MB05 and MB13) to be used as monitoring locations for this GWMP. Bore MB04 is located within the footprint of the Project and will likely be destroyed in the beginning of the mining operation. EA0002912 condition E7 states that a replacement bore for MB04 must be installed in the same coal seam immediately outside the north-east mining footprint and begin collecting data before the decommission of MB04.

EA0002912 condition E8 states that two bores must be installed to detect potential seepage down gradient from mine affected water dams MWD1 and MWD3 within six (6) months from the commencement of activities notified under condition A4 (October 1st 2021).The VCM monitoring network will be composed of selected bores (MB04, MB05, and MB13) from the current monitoring network, two locations based down gradient of mine affect water dams MWD1 and MWD3, and a replacement bore for MB04 immediately outside the north-east mining footprint. Once a replacement bore for MB04 has been installed, monitoring at MB04 can cease, and the bore can be decommissioned in accordance with the *Minimum construction requirements for water bores in Australia*.

Summary details for the Project monitoring network sites are presented in Table 5.1 and Figure 5.1.



LEGEND

- Vulcan ML 700060
- Vitrinite VCM Pit
- Proposed Vulcan Project - Vulcan area
- Adjacent mining project
- Proposed VCM monitoring bore
- Existing monitoring bore
- Existing exploration hole

DATE
08/02/2022

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Underground Water Monitoring Plan – Vulcan Coal Mine

Proposed Project monitoring network

FIGURE No.
5.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.

Z:\4000_Projects\4041_Metserve_Vulcan BSP Underground water monitoring program\3_GIS_pavel\GIS\workspaces\05_01_4041_Proposed_monitoring_network.qgz

Table 5.1 Project monitoring network – monitoring sites location

ID	Easting	Northing	Target unit	Casing height (maGL)	Casing elevation (mAHD)	Hole depth (mbGL)	Screen interval (mbGL)	EA required bore
MB2	622513	7534483	DLL coal seam	0.71	254.69	12.0	9.0 – 12.0	No
MB3	622668	7535017	DLL coal seam	0.70	257.68	33.8	30.8 – 33.8	No
MB4	622014	7536148	DLL coal seam	0.71	243.28	21.5	18.5 – 21.5	Yes
MB5	621964	7534905	MAT coal seam	0.77	252.7	40.9	37.9 – 40.9	Yes
MB13	622931	7533648	MAT coal seam	0.63	223.13	36.92	33.5 – 36.5	Yes
MB15	620134	7539063	MAT coal seam	n/a	n/a	n/a	n/a	No

The VCM groundwater monitoring network is designed to monitor and assess representative groundwater conditions in the coal seam aquifers (DLL and MAT). Access tracks for the proposed monitoring bore network will need to be developed and maintained to ensure safe access during the monitoring program.

5.1.1. Bore construction, maintenance and decommissioning

Any monitoring bores drilled and constructed for the VCM will be supervised by a water bore driller licensed by the Department of Regional Development, Manufacturing and Water (DRDMW). The monitoring bores are to be drilled and constructed in accordance with the *Minimum construction requirements for water bores in Australia*. The construction methodology should include reference to adequate sealing of the monitoring bore annulus to minimise potential contamination from the surface and to minimise vertical hydraulic connection between distinct aquifers at the site.

The monitoring methodology will include a physical inspection of the bore to assess for interference or damage. Groundwater monitoring will include the measurement of total bore depth during each sampling event. A measurement that is significantly different from the previous observation or bore construction data may indicate silting up or damage to the bore. Remedial works such as bore development or replacement of the bore may be required under these circumstances. Any monitoring bore that is abandoned or replaced shall be decommissioned in accordance with the *Minimum construction requirements for water bores in Australia*.

5.2. Parameters

The following groundwater level and groundwater quality parameters are to be monitored as part of the GWMP.

5.2.1. Standing water level monitoring

The groundwater levels in the monitoring bores listed in are to be measured via manual and automatic techniques to identify natural fluctuations in the groundwater system and to assess any hydraulic response resulting from the VCM.

5.2.2. Water quality monitoring

The groundwater quality in the monitoring bores listed in Table 5.1 are to be measured via field and laboratory methods to identify natural fluctuations in the groundwater system and to assess any change resulting from the VCM development. The individual groundwater quality parameters to be measured are listed in Table 5.2.

The field specific parameters to be analysed include pH and electrical conductivity (EC), the remainder of the parameters are laboratory specific. The eight heavy metal parameters included in Table 5.2 should be analysed in both total and dissolved forms. The interim trigger levels provided in Table 5.2, where specified, are consistent with the values provided in Table E2 of the EA.

Table 5.2 Groundwater quality parameter list and interim exceedance values

Parameter	Unit	Limit of Reporting	EA interim exceedance value
pH	-	0.01	5.5 – 8.0
Electrical conductivity (EC)	µS/cm	1	DLL coal seam (MB04): 12,849 MAT coal seam (MB5): 2,756 MAT coal seam (MB13): 3,000
Total dissolved solids (TDS)	mg/L	1	*na*
Na	mg/L	1	*na*
Ca	mg/L	1	*na*
Mg	mg/L	1	*na*
K	mg/L	1	*na*
Cl	mg/L	1	*na*
SO_4	mg/L	1	DLL coal seam (MB04): 1.76 MAT coal seam (MB5): 284 MAT coal seam (MB13): 398
Alkalinity (HCO_3, CO_3, OH)	mg/L	1.0	*na*
Al	mg/L	0.01	DLL coal seam (MB04): 4.8 MAT coal seam (MB5): 6.2 MAT coal seam (MB13): 6
Ag	mg/L	0.001	*na*
As	mg/L	0.001	0.013
Fe	mg/L	0.05	DLL coal seam (MB04): 288 MAT coal seam (MB5): 2.9 MAT coal seam (MB13): 2.8
Hg	mg/L	0.0001	0.0006
Mo	mg/L	0.001	0.034
Se	mg/L	0.01	0.005
Sb	mg/L	0.001	*na*
Total recoverable hydrocarbons (TRH) – C6-C9	mg/L	0.02	0.02
Total recoverable hydrocarbons (TPH) – C10-C36	mg/L	0.05	0.05

Notes: *The EA interim exceedance value is taken from Table E2 within the EA. The trigger values are generally set based on the maximum value plus 10%.*

Metals to be analysed for both dissolved and total.

Analytes with undefined (na) trigger levels to be collected in order to analyse all major ion ratios. Analytes not to be used as triggers.

5.3. Monitoring methodology

5.3.1. Monitoring frequency

The automatic water levels readings are recorded in 4 hours intervals, manual water level readings are recorded at time of water quality sampling.

In order to describe the ‘natural’ water quality baseline of the groundwater system and establish trigger values that are statistically robust, the DES water quality sampling guidelines (Department of Environment and Science - DES, 2021) recommend a number of sampling events and preferred length of baseline monitoring as “*…a minimum of 18 samples over at least 12 and preferably 24 months*” with eight samples as minimum to derive interim trigger values.

In accordance with the DES guidelines and the EA, it is recommended that the bi-monthly monitoring frequency remains as is for both established and new (proposed) observation locations. This will allow sufficient datapoints to evaluate natural conditions of the groundwater system sufficient to assess environmental impacts.

After evaluation of the baseline monitoring period and establishing the trigger values, the frequency of the water quality monitoring may be decreased to quarterly.

5.3.2. Standing water level monitoring

The groundwater levels in the monitoring bores are to be measured via manual and automatic techniques. The manual measurements are to confirm and validate the datalogger observations.

Manual

A manual groundwater level observation should be collected bi-monthly at each of the monitoring bores listed in Table 5.1. The general method for manual groundwater level measurement is as follows:

- ensure there is a defined location on the top of casing (preferable the PVC casing) from which to collect repeatable and representative measurements;
- remove the data logger from the bore and store in a cool place for download;
- measure and record the height of the top of casing (ToC) from ground level;
- measure and record the depth to groundwater (SWL) within the monitoring bore from the ToC;
- measure and record the total depth (TD) of the monitoring bore from the ToC;
- use SWL measurements taken from ToC to determine SWL from mAHD (EA level threshold reporting metric); and
- visually inspect the surface condition of the monitoring bore and record anything of note.

Groundwater level measurements should be collected using a commercial water level dipper with a graduated tape of centimetre accuracy. The water level dipper should be used and maintained in accordance with manufacturer’s instructions.

Data loggers

All the monitoring bores listed in Table 5.1 will be equipped with groundwater dataloggers or pressure transducers. The dataloggers will be setup to log every four (4) hours (daily scale monitoring). The dataloggers will be either vented or non-vented units which will be suspended in the monitoring bores at a measured depth below ToC. The general method for downloading groundwater dataloggers is as follows:

- Collect a manual groundwater level observation as per the method above.
- Measure and record the depth of datalogger installation or cable length.
- Retrieve the datalogger from the monitoring bore and download the data to a laptop or tablet. Use the specific datalogger software to connect and communicate with the datalogger. The removal of the datalogger will be required also for the water quality sampling.
- Ensure that the data can be visualised on the laptop or tablet and export the data to a csv or txt file.
- Check the battery level and memory of the datalogger.
- Re-install the datalogger into the monitoring bore following water quality sampling.

The dataloggers should be used and maintained in accordance with manufacturer's instructions. For non-vented dataloggers, the data will require barometric compensation and a barometric logger is already present within the VCM area. Barometric compensation is often carried out using the specific datalogger software and can be carried out in the office following the field measurement and sampling. The barometric logger is to be setup to record data every four (4) hours. All dataloggers (including the barometric logger) should be downloaded during each monitoring round.

5.3.3. Water quality monitoring

Purging

Groundwater samples from monitoring bores are required to be representative and repeatable. To achieve this, the groundwater that is collected for analysis needs to be sourced from the target aquifer and should not be a sample from the column of water within the bore that may be stagnant.

The bores should be purged to ensure that three bore volumes of groundwater are removed from the bore prior to collection of the laboratory sample. The field parameters of pH and EC should be monitored during purging to ensure stabilisation of the parameters has occurred. Appropriate purging methods for these bores include hand bailing, 12 volt submersible pumps or inertia pumps.

Where three bore volumes of groundwater are unable to be removed from the monitoring bore (in situations where there is low permeability or a limited water column in the bore) it may be appropriate to either dewater the bore during purging and return the next day to allow for recovery, or install a passive sampling technique such as a hydrasleeve. Hydrasleeves are installed in a number of monitoring bores in the Vulcan Complex Project monitoring network.

Field parameters and sample collection

As discussed above, appropriate purging methods for the monitoring bores include hand bailing, 12 volt submersible pumps or inertia pumps. The purging technique will also be used to provide the groundwater sample for field measurements and laboratory analyses.

The field parameters are generally monitored and recorded for two reasons:

- The monitoring of field parameters during the purging process assists in determining whether or not a stable or representative sample is being purged from the monitoring bore.
- There are several parameters which are affected by atmospheric conditions immediately after sampling. Notably pH should be assessed in the field as the laboratory holding time for pH is six hours, and this is generally breached by the time the sample is received by the laboratory.

The field water quality meter should be calibrated daily and in accordance with manufacturer's instructions. The meter should be calibrated using standard calibration solutions.

All laboratory samples should be collected in laboratory supplied sample containers appropriate for the required laboratory parameters. The sample bottles should be clearly labelled with the sample ID and date and time of sampling. The laboratory samples should be accompanied by a Chain of Custody (CoC) form to define the number of, and identity of the samples, the required parameters to be analysed and the persons or companies in control of the samples.

Field QA/QC

Field quality control and quality assurance (QA/QC) processes should be in consideration in respect of the following guidelines:

- Monitoring and Sampling Manual: Environmental Protection (Water) Policy 2009. Brisbane, Department of Environment and Science (DES, 2018);
- AS/NZ 5667 11 1998 - Water quality sampling. Part 11, guidance on sampling of groundwater (Standards Association of Australia & Standards New Zealand, 1998); and
- Australian Governments Groundwater Sampling and Analysis – A Field Guide (2009:27).

Currently a duplicate field sample is collected per monitoring round across the Vulcan Complex Project monitoring network to assess repeatability in the laboratory testing methods.

Storage/transport of samples

As discussed above, all laboratory samples should be collected in laboratory supplied sample containers appropriate for the required laboratory parameters. The samples should immediately be stored on ice, or refrigerated, and transported as soon as is reasonably practical to the laboratory for analysis. Samples should remain on ice or refrigerated during storage and transportation.

As discussed above, the laboratory samples should be transported under conditions documented in a chain of custody (CoC) form, to define the number of, and identity of the samples, the required parameters to be analysed and the persons or companies in control of the samples. It is important to note the laboratory holding times vary for individual analytes. The holding times represent the maximum time that a sample can be stored for representative analysis of a parameter. Transportation of samples should consider the holding times and the time taken for delivery of the samples to the laboratory from site.

Most laboratory sample bottles are plastic, however some parameters require glass bottles. Glass bottles should be packed (e.g. bubble wrap), stored and transported to minimise breakage.

Labels showing an adequate amount of information are necessary to prevent misidentification of samples. Paper labels or tags should be avoided, as they are susceptible to destruction when wet. Labels should include the following information, as a minimum:

- bore number;
- project name and number;
- signature or initials of sampler;
- date and time of sample collection; and
- type of preservation used.

Labels should be affixed to the sample container prior to or at the time of sampling. The labels should be filled out at the time of sample collection using a marker pen with indelible ink. The exact sample location and type of sample must be recorded on the CoC.

Laboratory analyses

The laboratory undertaking the analytical testing of groundwaters should be accredited by the National Association of Testing Authorities (NATA) for the requested analyses. The laboratory will typically have internal QA/QC protocols which will be reported as part of the analyses.

5.4. Monitoring equipment

5.4.1. Equipment

The various items of equipment to be used in the groundwater monitoring include the following:

- Sampling pump such as hand bailer, 12 volt submersible pump or inertia pump. Some pumps require on-going and regular maintenance to ensure trouble free operation.
- Data logger download cable and laptop.
- Groundwater level dipper. A groundwater level dipper does generally not require maintenance but will need regular cleaning and adequate spare batteries.
- Handheld water quality meter. The water quality meter will require regular charging or battery replacement, daily calibration (see Section 5.4.2 below) and general servicing as per manufacturer's instructions. Water quality probes (such pH) must be stored appropriately and checked daily.
- Standard calibration solutions. There is a shelf life and expiry date for calibration solutions.
- Esky or portable fridge.
- Multiple indelible pens.
- Laboratory supplied sample bottles (including spares).
- Nitrile gloves.
- Filters and syringes.

All equipment must be serviced and operated as per the manufacturer's instructions.

5.4.2. Calibration

The only monitoring equipment requiring calibration is the handheld water quality meter. The meter must be calibrated using standard calibration solutions for pH (e.g. 4 and 7) and EC (e.g. 1,280 µS/cm). The water quality meter should be calibrated on a daily basis and maintained as per the manufacturer's instructions. Calibration records should be maintained by the persons or company undertaken the monitoring for a minimum period of five (5) years.

5.5. Qualifications of personnel undertaking monitoring

Groundwater quality and standing water levels must be monitored by an appropriately qualified (trained) person.

5.6. Documentation and data management

5.6.1. Field sheets

Field sheet templates are to be used by the persons undertaking the groundwater monitoring. The field sheet templates have pre-defined areas in which to capture information and are useful prompts in the field. A field sheet should be completed for each monitoring bore and should be scanned and stored for future reference. The groundwater monitoring field sheets should capture and record the following data:

- project number and name;
- name of sampler and the date and time of monitoring;
- bore identification number and overall condition of bore;
- water level measurements (section 5.3.1);
- datalogger download (section 5.3.1);
- sampling method and purged volume; and
- field water quality parameters.

5.6.2. Laboratory documentation

Chain of custody

A chain of custody (CoC) record must be filled out and accompany every sample or group of individually identified samples to trace the sample possession from the time of collection. Laboratories will often provide their own CoC template for use. Copies of the CoC must be given to the laboratory on delivery of the samples and a copy must be kept on file. The CoC must contain the following information:

- project number and name;
- signature and name of sample collector;
- sample identification numbers;
- date and time of sample collection;
- number of containers and their type;
- method of transport;
- condition of samples when received by the laboratory;
- specific comments and remarks;
- date and time of each change of custody;
- signatures of people in the chain of custody sample handover; and
- list of parameters to be analysed for each sample.

Analytical reports

Laboratory analytical reports should be sent to the Vitrinite site representative and the nominated hydrogeologist for the VCM.

5.6.3. Data management

Monitoring records, reports and data associated with the groundwater monitoring plan should be kept until the surrender of Environmental Authority 0002912. Vitrinite should maintain two groundwater databases:

- a level database comprising manual and automated level logger results; and
- a quality database comprising field and laboratory quality results.

5.7. Exceedance investigation

5.7.1. Water quality monitoring

The water levels and water quality data should be processed and reviewed by Vitrinite within 24 hours of the data from each monitoring round becoming available, either by the subcontractor taking the water level measurements or from the accredited lab analysing the groundwater quality samples. Any inconsistencies, discrepancies, changes in trend or clear outliers should be flagged.

If groundwater measured at any monitoring bore specified in Table 5.1 exceeds the corresponding trigger limit in Table 5.2 on any three (3) consecutive sampling occasions, the EA holder must notify the administering authority via WaTERS within 24 hours of receiving the result.

If an exceedance of EA groundwater quality trigger values occurs, the environmental authority holder must undertake an investigation to determine that environmental harm has or may occur, and must:

a) implement immediate measures to reduce the potential for environmental harm;

b) develop and detail long-term mitigation measures to address any existing groundwater contamination and prevent recurrence of groundwater contamination; and

c) submit an investigation report to the administering authority within twenty-eight (28) days of the completion of investigation.

5.7.2. Water level monitoring

If groundwater level monitoring indicates that groundwater levels have dropped below the level threshold stated in EA0002912 table E3, the EA holder must:

- notify the administering authority within twenty-four hours;
- conduct an investigation into the cause of the exceedance within twenty business days; and
- if the mining activities are identified as a potential cause or contributor to the drawdown, the EA holder must take immediate action to ensure compliance with the conditions of this EA.

5.8. Review and update of the GWMP

Full review of GWMP will be undertaken every 12 months by qualified hydrogeologist. The GWMP update will include:

- full review of existing water levels and water quality data;
- full review of used sampling methodology; and
- re-evaluation of suitability of sampling methodology, including selection of monitoring sites, trigger values for individual analytes and sampling frequency.

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